ASSESSMENT OF ANTHROPOGENIC THREATS TO MARINE MEGAFAUNA IN THAILAND

A thesis submitted for Doctor of Philosophy (PhD) by

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ABSTRACT

Thailand is ranked among the top 20 nations in the world for capture fisheries production and is a popular destination for marine tourism providing the main sources of income and livelihoods for Thai coastal communities. However, rapid human population growth, migration and development of coastal areas have led to increased pressures from small-scale fisheries (SSF) and tourism focussing on marine megafauna (marine mammals, sea turtles and elasmobranchs) in coastal waters of Thailand. To date, effects of anthropogenic activities on marine megafauna in Thailand are poorly understood due to lack of research effort, effective assessment, monitoring and management. This thesis represents the first comprehensive evaluation of anthropogenic threats to marine megafauna in Thailand and includes a catch assessment of SSF using a questionnaire survey with fishers and an assessment of the effects of boat-based dolphin-watching tourism on Indo Pacific humpback dolphin (*Sousa chinensis*) behaviour using passive acoustic monitoring (PAM) combined with shore-based observations. The thesis focuses on three odontocete species: Indo-Pacific humpback dolphin, Irrawaddy dolphin (*Orcaella brevirostris*) and Indo-Pacific finless porpoise (*Neophocaena phocaenoides*); resident off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat in the central-western Gulf of Thailand, where the species are subjected to multiple anthropogenic threats including fisheries and marine tourism. The research provides the first independent investigation of odontocete occurrence and foraging occurrence using PAM and a new estimation of the abundance of Indo-Pacific humpback dolphins based on capture-recapture analysis of photo-identification data collected during boat-based surveys. The thesis results reveal that the level of marine megafauna catch in Thai SSF is of concern and likely unsustainable for some of the documented species and highlights the need for further investigation. PAM indicated relatively high acoustic activity of odontocetes in the central-western Gulf of Thailand, and in particular off Laem Thuat Pier, Don Sak, Surat Thani. Further, the results showed that the dolphin-watching tourism significantly affected the short-term behaviours of Indo-Pacific humpback dolphins at levels that may result in long-term negative impacts on both individual and population levels. Odontocete populations in the central-western Gulf of Thailand are threatened by a combination of human threats including fisheries catch, coastal construction, vessel traffic and tourisms. This thesis highlights the urgent need for better understanding and mitigation of the effects of these anthropogenic activities on marine megafauna in Thailand through further research, conservation and management. The results of the thesis provide an initial evidence base for initiation of conservation and management actions to safeguard the health of marine megafauna species in Thailand and odontocete populations in the central-western Gulf of Thailand and the ecosystem services they provide.

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THESIS OVERVIEW

1 | Background and Rationale

Thai coastal communities have been relying on marine fisheries and tourism as essential sources for food and livelihoods for generations (Teh et al. 2015a). A rapid expansion of the coastal communities and fisher populations in Thailand occurred after the 1960s (Teh et al. 2015a) and Thailand was ranked among the top 20 fishing nations in the world in terms of capture fisheries production in 2014 (FAO 2015). Thai fisheries contributed USD 3,560 million to the gross domestic product (GDP) (SEAFDEC 2019) and USD 5,495 million to export values in 2018 (DOF 2020) with an estimated production of 2.39 million tons in 2017 (SEAFDEC 2019). However, the consequence of overfishing and exploitation in the 1970s (Salayo et al. 2008; Teh et al. 2015a; Whitty 2015) with an addition of illegal fishing methods using dynamite and cyanide (Lunn & Dearden 2006; Suebpala et al. 2015; Teh et al. 2015a), have resulted in rapid depletion of marine resources and degraded marine environments reflected by decrease in marine fishery catch and fish consumption by coastal populations in recent decades (De Leon & Derrick 2020; Teh et al. 2015a).

To mitigate this negative trend, the coastal communities have adapted by seeking new economic opportunities including multipurpose fisheries and marine tourism activities (Teh et al. 2015a). As the interest in marine tourisms and wildlife observation have been rapidly increasing worldwide in the past 30 years (Chen 2011; Einarsson 2009; Higham et al. 2014), dolphin and whale watching have become popular tourist activities and alternative income sources for coastal communities (Berggren et al. 2007; Hoyt 2001; Mustika et al. 2017; Orams 2002), which attracted over 13 million people from over 119 countries (O’Connor et al. 2009) and valued over at USD 2.5 billion in yearly revenue supporting around 19,000 jobs worldwide

(Cisneros-Montemayor et al. 2010). The central-western Gulf of Thailand (consisting of Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat) is one of the dolphin-watching hotspots in Thailand (Adulyanukosol et al. 2012b; Jutapruet et al. 2015) attracting around 10,000 tourists and dolphin-watching enthusiasts yearly (Mustika et al. 2017).

Driven by the prevalent anthropogenic activities in the coastal areas, the pressure on marine resources is rising and threatening the survival of marine megafauna (marine mammals, sea turtles and elasmobranchs) (Bejder et al. 2006; Brownell Jr. et al. 2019; Dulvy et al. 2014; Lewison et al. 2014; Schoeman et al. 2020). Small-scale fisheries (SSF) are likely the greatest contributor to megafauna catch in Thailand with an estimated 56,001 (95% CI: 50,360 – 61,642) SSF vessels operating in Thai coastal waters in the Gulf of Thailand and the Andaman Sea in the period 2005 – 2018 (Chapter 1; FAO 2020). Thai SSF contributed an estimated 14% of the entire marine fisheries catch during 2015 – 2017 (De Leon & Derrick 2020), and gillnet fisheries were the dominant SSF practice (60%), which are also identified as the greatest threat to marine megafauna globally (Dulvy et al. 2014; Lewison et al. 2004; Lewison et al. 2014; Read et al. 2006; Reeves et al. 2013). Beside fisheries, dolphin and whale watching tourism have become a threat to cetacean populations as the activities have become more aggressive and more interactive toward the animals which may negatively affect their behaviours (Christiansen et al. 2010; Filby et al. 2014; Nowacek et al. 2001), welfare and survival (Bejder et al. 2006; Lusseau et al. 2006; Stone & Yoshinaga 2000).

Despite this, little is known about the interactions between marine megafauna and anthropogenic activities in Thailand such as SSF and dolphin-watching tourism due to very few research publications and reports, and lack of comprehensive assessments (Hines et al. 2020; Mustika et al. 2017; Mustika et al. 2021; Verutes et al. 2020). There is further no centralised bycatch database available making it difficult to conduct assessment of the potential impact from bycatch on vulnerable megafauna necessary for creating conservation and management strategies. Failure to identify where conservation and management actions are necessary will likely drive many endangered and vulnerable coastal megafauna species to extirpation.

2 | Thesis Summary

2.1 Chapter 1

The first thesis chapter aims to provide an overview of cetacean catch in small-scale fisheries (SSF) in Southeast Asia. The Food and Agriculture Organisation (FAO) official fishing vessels statistics were used to estimate and compare the fishing effort measured as the number of SSF vessels declared by nine nations in Southeast Asia during 2005 – 2018 (FAO 2020a). Fishing effort was classified into four métiers (gear types) based on the declared SSF gear types: gillnets, longlines, other lines and traps. Between 2005 and 2018, the mean number of SSF vessels were estimated worldwide to 4,081,922 (95% CI: 4,021,158 – 4,142,686), of which 1,385,344 (1,342,679 – 1,428,009) or 34% were in Southeast Asia (FAO 2020a). Indonesia had the highest estimated mean number of SSF vessels [580,485 (95% CI: 547,576 – 613,394)] representing 41.9% of the number of vessels in Southeast Asia, while 56,001 (95% CI: 50,360 – 61,642) (4.0%) was estimated for Thailand. Gillnets, longlines, other lines and traps were used by 21.2%, 65.4%, 7.3% and 6.1%, respectively of the Southeast Asian fishers. Cetacean bycatch in Southeast Asian SSF is poorly investigated and there is a near complete lack of bycatch information for the region (both quantitative and qualitative) highlighting the need for further comprehensive investigation and assessment.

2.2 Chapter 2

With a complete lack of data for marine megafauna catch in Thai small-scale fisheries (SSF), the research conducted in Chapter 2 represents the first independent assessment in Thailand. Catch data were collected from 535 face-to-face questionnaire-based interviews with the SSF fishers during September – December 2017 in 32 fishing communities across 17 provinces in the Gulf of Thailand and the Andaman Sea. Catch composition and catch per unit effort (CPUE) data derived from the interviews were combined with official fisheries effort statistics (DOF 2016) to estimate annual total catch per megafauna species group. The results revealed that the mean annual estimated catches were 5,662,024 (95% CI: 4,097,779 – 7,817,707) rays, 457,864 (95% CI: 192,352 – 969,166) sharks, 2,400 (95% CI: 1,610 – 3,537) sea turtles, 790 (95% CI: 519 – 1,167) cetaceans and 72 (95% CI: 19 – 194) dugongs in Thai SSF in 2016 – 2017. In the Gulf of Thailand: crab gillnets had the highest CPUEs for rays, sharks and cetaceans; pound nets for sea turtles; and ray gillnets for dugong. In the Andaman Sea: crab gillnets also had the highest CPUEs for rays and sharks; squid trammel nets for sea turtles; and shrimp trammel nets for cetaceans and dugong. The mean annual estimated catches should be considered as minimum estimates as a number of fishing gears reported by the fishers in the questionnaire were excluded from the extrapolation as they did not occur in the Thai official fisheries statistics (DOF 2016). The resultant estimated catch and compositional data from this chapter highlights the need for a follow-up comprehensive assessment of marine megafauna catch in Thai SSF using observed landings and/or onboard observer/remote electronic monitoring data to allow impact assessment of the catch on respective marine megafauna species. This chapter provides the necessary baseline data and evidence to plan and prioritise future research and assessment of SSF catch of marine megafauna in Thailand.

2.3 Chapter 3

Passive acoustic recordings have been applied to study the vocal repertoire of wild and captive odontocetes in Thailand (Niu et al. 2021; Niu et al. 2019; Svarachorn et al. 2016). However, Chapter 3 is the first investigation to use Passive Acoustic Monitoring (PAM) to investigate the spatio-temporal variation in occurrence and foraging occurrence of three sympatric coastal odontocete species: Irrawaddy dolphin (*Orcaella brevirostris*), Indo-Pacific humpback dolphin (*Sousa chinensis*) and Indo-Pacific finless porpoise (*Neophocaena phocaenoides*) in the central-western Gulf of Thailand (Jutapruet et al. 2017). PAM was conducted during eight months from May to September 2019 and February to April 2020 off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand. Cetacean click recorders (C-PODs) (Chelonia.co.uk 2019) were deployed at three locations across the study area and used to record echolocation click vocalisations produced by odontocetes. Currently, the C-POD software cannot differentiate clicks from the three species studies. Therefore, this study investigated variation in odontocetes rather than the individual species. Occurrence and foraging occurrence were analysed with respect to spatial (site) and temporal (hour, month, tide phase and moon phase) factors using Generalised Additive Models (GAMs). Laem Thuat Pier showed the highest levels of occurrence and foraging occurrence possibly influenced by the nutrient-rich water entering the area from the Don Sak River providing high productivity and availability of dolphin prey. The GAM analyses showed that the four temporal abiotic environmental factors significantly influenced the odontocete occurrence at all three sites, while the influence on foraging occurrence varied among sites. The results indicate that the area off Laem Thuat Pier is an important area for odontocete occurrence and foraging occurrence. Given the multitude of anthropogenic threats facing odontocetes in the study area, conservation and management actions are recommended to ensure the animals are protected in the area off Laem Thuat Pier.

Chapter 3 provides valuable insights with a recommendation for using PAM as a future reliable and consistent monitoring system for odontocete occurrence.

2.4 Chapter 4

The research conducted in Chapter 4 applies concurrent data sampling from shore-based observations and passive acoustic monitoring to investigate potential effects of boat-based dolphin-watching tourism on surface and acoustic behaviours of Indo-Pacific humpback dolphins (*Sousa chinensis*). Observations of Indo-Pacific humpback dolphins and dolphin-watching tourism boat activities were conducted during 55 days between February and April 2020 at Laem Thuat Pier, Don Sak, Surat Thani, Thailand. The shore-based observations were conducted using focal group follows to observe and record dolphin surface behaviours, while a cetacean echolocation click recorder (F-POD) (Chelonia.co.uk 2020) was deployed off Laem Thuat Pier to collect data on the vocalisation activities produced by Indo-Pacific humpback dolphins. The synchronous visual and acoustic data were analysed and compared between the times when tourist boats were present and absent. The results showed that dolphins significantly decreased the proportion of time spent resting (from 42% to 23%) and staying silent (from 79% to 71%), and significantly increased the proportion of time spent socialising (from 14% to 17%), travelling (from 3% to 22%) and producing regular echolocation clicks (from 18% to 26%) when tourist boats were present. Dolphins were more likely to start travelling and less likely to stay foraging, resting, socialising and vocalising in the presence of tourist boats as inferred from the results of Markov chain analyses. Chapter 4 demonstrated that the tourism activities off Don Sak affected the short-term behaviours and vocalisations of dolphins, which may reduce their fitness at both individual and population levels. Chapter 4 highlights the need for management to minimise potential long-term negative effects on the dolphins and to ensure the sustainability of dolphin-watching tourism as an important economic activity off Don Sak, Surat Thani, Thailand.

2.5 Chapter 5

A new estimation of the abundance of Indo-Pacific humpback dolphins inhabiting the coastal areas off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand is provided in this final data chapter of the thesis. Boat-based surveys were conducted during May – July 2019 to collect photo-identification data of Indo-Pacific humpback dolphins used for capture-recapture analyses. A new abundance estimate was generated using closed capture-recapture models (Otis et al. 1978; White 2008). The resulting abundance estimate for Indo-Pacific humpback dolphins off Don Sak and Khanom was 52 (95% CI: 49 – 62) non-calf individuals. The new abundance estimate was very similar to an estimate from 2010 of 49 animals (no reported 95% CI) (Jaroensutasinee et al. 2010) and lower than a 2015 estimate of 193 (95% CI 167 – 249) (Jutapruet et al. 2015). It is unclear what may have caused the apparent fluctuation in numbers in 2010, 2015 and 2019, and a re-analysis using the data from all three studies would possibly help clarify the difference in abundance among years. Chapter 5 also discuss the new estimate of abundance in relation to the ongoing anthropogenic threats to the dolphins in the study area. Although survival rate and prediction for potential extirpation cannot be estimated due to limited available data, the low abundance of Indo-Pacific humpback dolphin in the study area suggests that the species may be at risk. Future systematic research with greater effort covering broader spatio-temporal scales to create long-term, consistent and comparable data for Indo-Pacific humpback dolphins and the other odontocete species in the study area is highly recommended.

2.6 Chapter 6

Chapter 6 represents the conclusions of the thesis and recommendations for future conservations and managements of megafauna and small-scale fisheries in Thailand. The thesis as a whole represents the first independent investigation on the effects of anthropogenic activities on marine megafauna in Thailand, particularly on coastal odontocetes. The thesis provides baseline data for future research and represents an important evidence-base for identified future conservation and management actions to safeguard the marine megafauna species/populations in Thailand. Chapter 6 concludes that if the current levels of anthropogenic pressures in Thailand continues without any effective mitigation, conservation or management, a number of marine megafauna species will likely face extirpation or extinction.

3 | Research Questions

Chapter 2: What are the catch number and catch composition of marine megafauna in small-scale fisheries in Thailand?

Chapter 3: What are the environmental drivers for the spatio-temporal patterns in occurrence and foraging occurrence of odontocetes off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, central-western Gulf of Thailand?

Chapter 4: Do boat-based dolphin-watching tourism activities affect surface and acoustic behaviours of Indo-Pacific humpback dolphins off Don Sak, Surat Thani, Thailand?

Chapter 5: What is the current abundance of Indo-Pacific humpback dolphins off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand?

CHAPTER 1

Overview of Cetacean Bycatch in Small-Scale Fisheries in Southeast Asia

1.1 | Abstract

Fisheries bycatch represents the greatest threat to cetaceans. However, the majority of bycatch investigation tend to focus on industrial fisheries, while those for small-scale fisheries (SSF) has been generally overlooked because SSF are typically operated by local fishing communities in coastal remote areas, where monitoring and management are limited. Despite Asia has the greatest fisheries outputs and the largest markets for fishery products, little is known about the SSF efforts and cetacean bycatch activities. This is especially true in Southeast Asia where there are large SSF fleets and cetacean bycatch has been reported in many nations, whilst systematic assessment is limited, and successful mitigation and conservation are yet to be initiated. This chapter reviews the SSF effort in Southeast Asia using the FAO official fishing vessels statistics and collate available cetacean bycatch data in Southeast Asia through available literature source. Globally, there were an estimated 4,081,922 (95% CI: 4,021,158 – 4,142,686) SSF vessels in 2005 – 2018, of which 1,385,344 (1,342,679 – 1,428,009) or 34% where located in Southeast Asia. Indonesia had the largest SSF vessel effort [580,485 (95% CI: 547,576 – 613,394)] (41.9% of all SSF vessels in Southeast Asia) while Thailand was at the fourth ranked [56,001 (95% CI: 50,360 – 61,642)] (4.0%). Indonesia had the highest SSF effort for all four gear types: gillnets, longlines, other lines and traps. Gillnets, longlines, other lines and traps were used by 21%, 65%, 7% and 6%, respectively of Southeast Asian fishers. The very limited available data on bycatch information represents the main problem hindering further research and management in Southeast Asia.

1.2 | Introduction

Fisheries are the greatest anthropogenic threat to cetaceans (dolphins, whales and porpoises) (Read et al. 2006; Reeves et al. 2013). This is the result of a global occurrence of fisheries related catch and bycatch (unintentional catch), which have been a major cause of cetacean mortality in the past 40 years (Lewison et al. 2014; Reeves et al. 2013). Coupled with low growth and low reproductive rates (Pianka 1970), serious concerns for cetacean welfare and survival have been raised, especially for the coastal species as they are continuously exposed to small-scale fisheries (SSF) (Brownell Jr. et al. 2019; Reeves et al. 2013), which are prevalently operated within the coastal areas overlapping odontocete species' distribution (Temple et al. 2021). Despite the threats posed, the majority of bycatch assessment and research tend to focus on large-scale, commercial or industrial fisheries in high-income nations (Lewison et al. 2014; Read et al. 2006; Reeves et al. 2013), while SSF have largely been overlooked, particularly in relatively low-income or developing nations (Andrew et al. 2007). This chapter will explore the current knowledge of SSF in Southeast Asia through official fisheries statistics (primarily FAO 2020). Available information on fishing effort and catch/bycatch of cetaceans will be summarised and potential knowledge gaps will be identified to inform future works.

1.3 | A brief overview of global small-scale fisheries

SSF can be broadly characterised as fishing practices to exploit marine fishery resources for subsistence consumption and supplying fishery products to local or domestic markets (Béné 2006; Lymer et al. 2008). SSF occur worldwide but are particularly common and dominant in developing nations (Gillett 2011). SSF operate at widely differing organisational levels ranging from self-employed single operators through informal microenterprises to formal sector businesses (FAO 2021b). SSF are not homogeneous within and across countries and regions

(FAO 2021b), and involve the usage of different types of vessels and gears, but generally involve vessels: < 10 m; < 10 gross tonnage; < 60 horsepower; 1 – 3 crews; and using nets, lines and traps (Chuenpagdee & Pauly 2008; Lymer et al. 2008; Teh & Pauly 2018).

There are neither reliable global estimates of the number of people dependent on SSF, nor reliable assessments of their role in national or regional economies (Béné 2006). Nevertheless, a total SSF catch was globally estimated to 42 million tons per year (FAO 2020b). It was further estimated that the SSF sector, including fishing and farming, employed around 37 million people (FAO 2021b), of whom 32 million (86%) were classified as SSF fishers (FAO 2021a) and around 33 million (90%) of all employed people were in Asia (FAO 2021b). An additional 100 million people were estimated employed and involved in associated activities (e.g. fishing and post-harvest sector) (FAO 2021a; FAO 2021b). Furthermore, it was estimated in the official statistics that millions of non-fisher were also involved in seasonal or occasional fishing activities, and more than 200 million people worldwide estimated depending on SSF for their livelihood, of which many millions are in Asia (FAO 2021a).

1.4 | Small-scale fisheries in Southeast Asia

SSF are considered the backbone of socio-economic well-being providing food and jobs for the coastal communities in the Southeast Asian nations for the past century (Béné 2006; FAO 2021b; Teh & Pauly 2018). Fish is a crucial nutritional source of protein and other essential micronutrients for millions of people in Southeast Asia. Meanwhile, overexploitation has been causing habitat degradation and declined marine resources leading to lower catch contribution and fish consumption after 1970s (Teh & Pauly 2018; Teh et al. 2015b). SSF are difficult to quantify as they are operating in remote coastal areas and poorly monitored due to accessibility difficulties or low prioritisation overshadowed by industrial fisheries (Béné 2006), resulting in limited documentation and management of SSF in Southeast Asia. In regions where SSF information are generally lacking, understanding of the basic element of fishing effort is an essential first step for SSF bycatch assessment and management. In this overview, SSF fishing effort in Southeast Asia will be investigated using the Food and Agriculture Organisation (FAO) official fishing vessel statistics (FAO 2020a).

1.4.1 Estimation of small-scale fisheries efforts in Southeast Asia: methods

SSF vessel numbers were explored through the FAO official fishing vessel statistics from 2005 to 2018 (FAO 2020a). Of the 11 Southeast Asian countries, Laos is the only country that is not directly connected to the sea and the FAO statistics (FAO 2020a) does not have data available for Timor-Leste. Therefore, these two countries were not included in the analyses.

SSF vessel numbers were collated for each nation. First, all vessels with the length < 12 m or reported as "Unknown" were assumed to be SSF vessels for the purpose of the analyses. Second, SSF vessels in each country were categorised into four categories based on the declared SSF gear types: "Gillnets," "Longlines," "Other lines" and "Traps". In this step, the two declared vessel categories: "Multipurpose vessels" and "Other fishing vessels"; which represented the categories with a mixture of gears including the four gear types, were ignored and added later (see below). Third, the proportions of gillnets, longlines, other lines and traps were calculated across nations for each year (2005 – 2018). Fourth, the total number for each one of the four gear types per nation and year was estimated by assigning the percentages of "Multipurpose vessels" and "Other fishing vessels" as gillnets, longlines, other lines and traps, and adding these to the number of the corresponding gear types originally declared. Finally, the means and 95% confidence intervals of the estimated vessel numbers for each gear type and nation were calculated over the period from 2005 to 2018. For the purpose of the analyses, the estimation in this chapter was based on the assumption that all nine nations in Southeast Asia region are likely to have similar characteristics of SSF vessels and fishing practices.

Table 1.1 Estimated number (mean and 95% confidence interval) of small-scale fisheries vessels in southeast Asia from 2005 to 2018 based on the FAO official fishing vessels statistics (FAO 2020a)

Rank	Country	Number of vessels: mean (95% CI)		%
1	Indonesia	580485	(547576 – 613394)	41.9
2	Philippines	452874	(427711 – 478037)	32.7
3	Cambodia	205163	(199821 – 210506)	14.8
4	Thailand	56001	(50360 – 61642)	4.0
5	Malaysia	38795	(35529 – 42062)	2.8
6	Vietnam	25012	(23151 – 26872)	1.8
7	Myanmar	24265	(18834 – 29696)	1.8
8	Brunei	2621	(2283 – 2958)	0.2
9	Singapore	128	(120 – 136)	< 0.1
	Total	**1385344**	**(1342679 – 1428009)**	

Table 1.2 Estimated number (mean and 95% confidence interval) of small-scale fisheries vessels using four gear types: gillnets, longlines, other lines and traps; in southeast Asia from 2005 to 2018 based on the FAO official fishing vessels statistics (FAO 2020a)

Rank	**Country**	**Number of vessels using gillnets: mean (95% CI)**		**%**
1	Indonesia	118929	(107524 – 130334)	40.5
2	Philippines	92776	(84224 – 101328)	31.6
3	Malaysia	30957	(27769 – 34146)	10.6
4	Cambodia	19700	(17884 – 21516)	6.7
5	Thailand	15073	(10617 – 19530)	5.1
6	Myanmar	10121	(8484 – 11758)	3.5
7	Vietnam	5170	(4404 – 5935)	1.8
8	Brunei	521	(498 – 544)	0.2
9	Singapore	51	(45 – 58)	< 0.1
	Total	**293157**	**(264103 – 322212)**	

Rank	**Country**	**Number of vessels using longlines: mean (95% CI)**		**%**
1	Indonesia	381060	(352974 – 409146)	41.9
2	Philippines	297381	(275878 – 318885)	32.7
3	Cambodia	172146	(167581 – 176711)	18.9
4	Thailand	33716	(30601 – 36830)	3.7
5	Vietnam	16270	(14699 – 17841)	1.8
6	Myanmar	5233	(794 – 9672)	0.6
7	Brunei	1759	(1425 – 2093)	0.2
8	Malaysia	1430	(1332 – 1529)	0.2
9	Singapore	62	(58 – 66)	< 0.1
	Total	**906244**	**(847595 – 964892)**	

Rank	**Country**	**Number of vessels using other lines: mean (95% CI)**		**%**
1	Indonesia	45232	(38124 – 52339)	45.3
2	Philippines	35192	(29949 – 40436)	35.2
3	Cambodia	7473	(6359 – 8586)	7.5
4	Malaysia	5386	(4694 – 6077)	5.4
5	Thailand	3971	(3222 – 4720)	4.0
6	Vietnam	1992	(1579 – 2404)	2.0
7	Myanmar	511	(50 – 972)	0.5
8	Brunei	194	(179 – 209)	0.2
9	Singapore	8	(6 – 10)	< 0.1
	Total	**101402**	**(86837 – 115966)**	

Rank	**Country**	**Number of vessels using traps: mean (95% CI)**		**%**
1	Indonesia	35264	(24606 – 45922)	42.5
2	Philippines	27524	(19149 – 35900)	33.2
3	Myanmar	8400	(5773 – 11027)	10.1
4	Cambodia	5845	(4066 – 7623)	7.0
5	Thailand	3241	(1938 – 4545)	3.9
6	Vietnam	1581	(1093 – 2068)	1.9
7	Malaysia	1021	(906 – 1136)	1.2
8	Brunei	146	(104 – 187)	0.2
9	Singapore	6	(4 – 9)	< 0.1
	Total	**84576**	**(59689 – 109463)**	

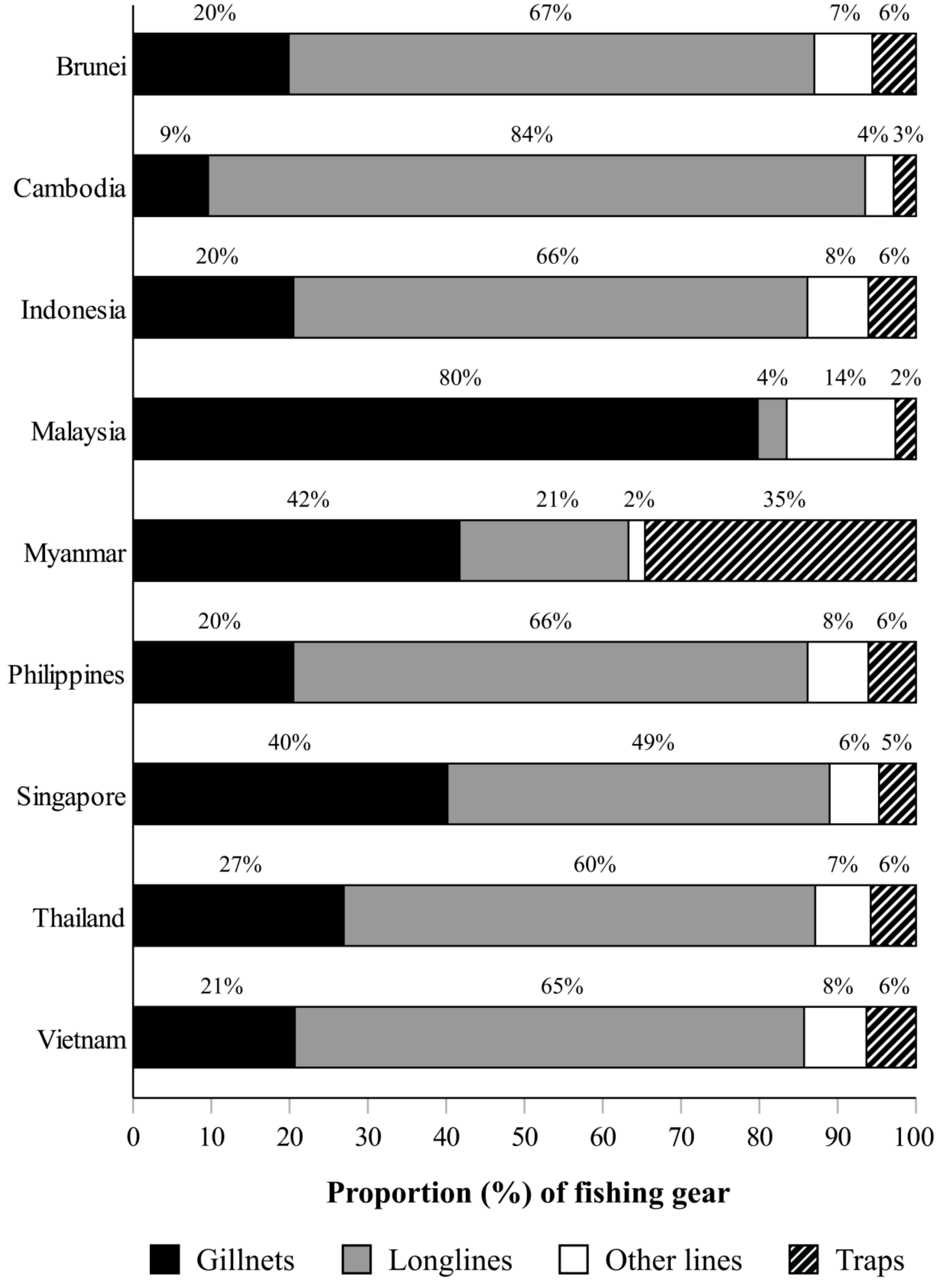


Figure 1.1 Proportion of small-scale fisheries vessels using four gear types: gillnets, longlines, other lines and traps; in southeast Asia from 2005 to 2018 based on the FAO official fishing vessels statistics (FAO 2020a)

Table 1.3 Estimated number (mean and 95% confidence interval) of small-scale fisheries vessels by gear type in Thailand from 2005 to 2018 based on the FAO official fishing vessels statistics (FAO 2020a)

Rank	Gear	Number of vessels: mean (95% CI)		%
1	Longlines	33716	(30601 – 36830)	60.2
2	Gillnets	15073	(10617 – 19530)	26.9
3	Other lines	3971	(3222 – 4720)	7.1
4	Traps	3241	(1938 – 4545)	5.8
	Total	**56001**	**(50360 – 61642)**	

1.4.2 Estimation of small-scale fisheries effort in Southeast Asia: results

The mean estimated number of SSF vessels worldwide based on data reported to FAO (2020a) between 2005 and 2018 was 4,081,922 (95% CI: 4,021,158 – 4,142,686), of which 1,385,344 (1,342,679 – 1,428,009) or 34% were in Southeast Asia. The data show that Indonesia, the largest country in Southeast Asia, had the largest SSF vessel effort [580,485 (95% CI: 547,576 – 613,394)] (41.9% of all SSF vessels in Southeast Asia) while Thailand was ranked fourth [56,001 (95% CI: 50,360 – 61,642)] (4.0%) (Table 1.1). The estimation by gear type showed that Indonesia had the highest SSF effort for all four gear types: gillnets (40.5%), longlines (41.9%), other lines (45.3%) and traps (42.5%) while Thailand was ranked fifth in SSF effort for gillnets (5.1%), other line (4.0%) and traps (3.9%), and ranked fourth for longlines (3.7%) (Table 1.2).

Gillnets, longlines, other lines and traps were used by 21%, 65%, 7% and 6%, respectively of Southeast Asian fishers according to the data reported to FAO between 2005 and 2018 (FAO 2020a) (Table 1.2). Nevertheless, each gear type was used by different proportion of fishers in each country. Longlines had the highest proportion used by fishers with 54% (4 – 84%), followed by gillnets, traps and other lines with the proportions of 31% (9 – 80%), 8% (2 – 35%) and 7% (2 – 14%), respectively (Figure 1.1). Longlines were a dominant fishing gear in all countries except in Malaysia and Myanmar where gillnets were instead (Figure 1.1).

1.4.3 Estimation of small-scale fisheries effort by gear type in Thailand: results

Based on data reported to FAO (2020a) between 2005 and 2018, the highest mean estimated number of SSF vessels by gear type in Thailand was longlines [33,716 (95% CI: 30,601 – 36,830)] (60.2%). Gillnets were ranked second [15,073 (95% CI: 10,617 – 19,530)] (26.9%), followed by other lines [3,971 (95% CI: 3,222 – 4,720)] (7.1%), and traps [3,241 (95% CI: 1,938 – 4,545)] (5.8%), respectively (Figure 1.1 and Table 1.3).

1.5 | Overview of global cetacean bycatch in small-scale fisheries

Fisheries bycatch is a global issue and represents the greatest threat to cetaceans (Avila et al. 2018; Read 2008; Read et al. 2006; Reeves et al. 2013). Bycatch is considered one of the main causes of anthropogenic mortality for cetaceans (Lewison et al. 2004; Read et al. 2006; Reeves et al. 2013), and it was estimated that over 300,000 cetaceans are killed or seriously injured annually in fisheries worldwide (Read et al., 2006). However, available information of cetacean bycatch in SFF worldwide is limited (Basran & Sigurðsson 2021; Jog et al. 2022; Lewison et al. 2014; Read et al. 2006; Reeves et al. 2013) as SSF generally occur in coastal and remote areas where monitoring, management and enforcement are limited (Lunn & Dearden 2006; Mintzer et al. 2018; Teh et al. 2015b; Whitty 2015). Further, the concept of bycatch may have limited relevance to SSF in developing countries such as those in Southeast Asia, where most captures have economic value and can become targeted resources to support the livelihoods of coastal communities (Teh et al. 2015b).

SSF bycatch is difficult to detect and usually neglected unless fishing vessels have dedicated onboard scientific/authoritative observers (Komoroske & Lewison 2015). Bycatch information can be obtained via several sources: fisher logbooks (Basran & Sigurðsson 2021), landing observation at local ports (Temple et al. 2019) or direct interviews with the fishers (Moore et al. 2010). Although cetaceans are legally protected in many countries (Basran & Sigurðsson 2021), it is difficult to monitor, quantify and manage catch and bycatch because fishers can easily discard the evidence of catches to avoid reprehension, and may deliberately not report, underreport or falsify their catch in logbooks or when interviewed by the authorities (Basran & Sigurðsson 2021; Mintzer et al. 2018). The illegal nature of the catch (notably of cetaceans) subsequently leads to underreporting and poor coverage in the literature, which typically cover a fraction of total fishing efforts (Lewison et al. 2004; Moore et al. 2009; Moore et al. 2010). Investigations by Basran &Sigurðsson (2021) revealed that reported cetacean bycatch by scientific observers were on average 7,348% higher in nets and 1,725% higher in hook and lines compared to catches reported in logbooks. The average annual estimated cetacean Catch Per Unit Effort (CPUE) based on observer data was 779% higher in net fisheries and 754% higher in line fisheries compared to the CPUEs based on the fisher logbook data in New Zealand and were up to 26,920% higher in gillnet fisheries in Iceland comparing observer and fisher logbook data (Basran & Sigurðsson 2021). In the United States, the mean estimated annual numbers of bycatch/injured cetaceans based on observer data were 2,696% higher in hook and line fisheries, and 1,365% in net fisheries, compared to that reported in fisher logbooks (Basran & Sigurðsson 2021).

Studies have shown that several cetacean species, including the Vaquita (*Phocoena sinus*) (Jaramillo Legorreta et al. 2019; Taylor et al. 2017) and North Atlantic right whale (*Eubalaena glacialis*) (Kenney 2018; Moore et al. 2021b) have been driven close to extinction due to fisheries bycatch. Another example is the Baiji (*Lipotes vexillifer*), a small cetacean species distributed in the Yangtze River, China, which was declared functionally extinct in 2006 as a result of unsustainable bycatch coupled with other anthropogenic activities (Turvey et al. 2007). Anthropogenic mortalities of cetaceans are mainly caused by fisheries bycatch due to fishing gear entanglements. Even when not fatal, entanglements can potentially have negative impacts on the individual, such as induced stress, decreased growth, depressed immune system function and reduction of reproductive success which will consequently have a negative effect on population and species (Robbins & Mattila 2001; Rolland et al. 2017).

1.6 | Cetacean bycatch in small-scale fisheries in Southeast Asia

Southeast Asia has been identified as a hotspot where cetacean species are driven close to extinction by fisheries bycatch coupled with a number of other anthropogenic threats (Brownell Jr. et al. 2019; Davidson et al. 2012; Temple et al. 2021). The extensive occurrence of SSF fleets with 34% of the entire global SSF fleet present in Southeast Asia (FAO 2020a) creates an enormous anthropogenic pressure on marine resources. However, there is currently limited information available on cetacean bycatch in SFF worldwide (Anderson et al. 2020; Jog et al. 2022; Lewison et al. 2014; Read et al. 2006; Reeves et al. 2013) and notably in Southeast Asia (Hines et al. 2020; Mustika et al. 2021; Temple et al. 2021). Although currently available statistics indicate that SFF may contribute less than industrial fisheries to the global cetacean annual bycatch, they are far more numerous and ubiquitous than their industrial counterparts (FAO 2020a) and their catch rate is high and unsustainable where they have been assessed (Alfaro-Shigueto et al. 2010; Brownell Jr. et al. 2019; Mangel et al. 2010). Moreover, SSF are primarily concentrated to coastal areas where they have a significant overlap with feeding and nursing grounds of coastal cetacean species, and thus increase the anthropogenic pressure and put the animals at risk of extirpation or extinction (Brownell Jr. et al. 2019; D'Agrosa et al.

2000; Taylor et al. 2017; Temple et al. 2021). Cetacean bycatch in SSF may be as important as bycatch in industrial fisheries, but a nearly complete lack of bycatch data (both quantitative and qualitative) for SSF in Southeast Asia make comprehensive assessment difficult.

The magnitude of SSF bycatch of cetaceans in terms of numbers, rates, impact on populations and mitigating strategies is currently unavailable and underexplored in every Southeast Asian nation as SSF are generally poorly documented, poorly monitored and unregulated in the region (Acebes et al. 2015; Anderson et al. 2020; Mustika et al. 2021; Teh et al. 2011). Similar to other regions, if reported, SSF bycatch is generally underreported or underestimated (Acebes et al. 2015; Mustika et al. 2014) and has not been systematically investigated on a national scale in any Southeast Asia country (Adulyanukosol et al. 2012a; Anderson et al. 2020; Hines et al. 2020; Reeves et al. 2013; Verutes et al. 2020). It is imperative to understand the magnitude of cetacean bycatch and cetacean interaction with fisheries to implement sustainable fishing practices and conserve cetacean populations. A systematic and comprehensive assessment of cetacean bycatch across Southeast Asia (quantitatively and qualitatively) would be of immense scientific value facilitating for future conservation strategies (Alfaro-Shigueto et al. 2010; Hines et al. 2020; Verutes et al. 2020; Whitty 2015).

A few initial studies have provided quantitative cetacean bycatch estimates through extrapolation of available fishery statistics (Anderson et al. 2020; Reeves et al. 2013), that clearly highlight the magnitude of the bycatch problem while demonstrating the issue of limited available data in Southeast Asia (Table 1.4). However, the estimated annual cetacean bycatch presented in Table 1.4 (Anderson et al. 2020) was from tuna gillnet fisheries in Indian Ocean which did not include SSF bycatch, and therefore does not quantitatively represent the current cetacean bycatch situation in Southeast Asian SSF. Many cetacean species are currently listed as Critically Endangered, Endangered and Vulnerable by the International Union for Conservation of Nature (IUCN) Red List of Threatened Species, and their survival is continuously threatened by fisheries bycatch in combination with numerous other anthropogenic activities (Brownell Jr. et al. 2019; Lewison et al. 2004). To reverse the trend and to make sure no more species face extirpation and/or extinction, immediate actions are necessary and mitigation of cetacean bycatch should be on the top of the action list.

Table 1.4 Estimated annual cetacean bycatch in tuna gillnet fisheries by five Southeast Asian nations in Indian Ocean during 2012 – 2016. Modified from Anderson et al. (2020).

Rank	Country	Estimated annual cetacean bycatch: mean (± 50%)	
1	Indonesia	10704	(5352 - 16057)
2	Myanmar	484	(242 - 726)
3	Malaysia	458	(299 - 687)
4	Thailand	42	(21 - 63)
5	Timor-Leste	0	(0 - 1)
Total		**11688**	**(5844 - 17532)**

1.6.1 Gillnet fisheries: the greatest threat

Gillnets are commonly used by SSF fishers because they can be operated (set and retrieved) from small vessels without requiring expensive or complex equipment, or specialised skills — although knowledge and experience are necessary to find and catch targeted species. Given the characteristics of gillnets with different mesh sizes from small to large, these also risk catching non-target species such as small and large cetaceans (Amir et al. 2002; D'Agrosa et al. 2000; Reeves et al. 2013).

Gillnet entanglements usually lead to mortality particularly for small cetaceans that are inexperienced, vulnerable and cannot free themselves from the gears (Brownell Jr. et al. 2019; Dolman & Moore 2017; Taylor et al. 2017). Gear entanglements were suggested as the main cause for 550+ cetacean stranding cases in Thailand during 1993 – 2009 (Adulyanukosol et al. 2012a). Because SSF are commonly operated in coastal areas and set in shallow waters with low visibility (especially in river delta and estuaries) (Torregroza-Espinosa et al. 2020; Wang et al. 2019a), coastal cetaceans are at risk of entanglement as they are unlikely to see or avoid the gears in time (Kastelein et al. 2000). Although odontocetes use echolocation and mysticetes use limited hearing to detect and interpret objects (Au 2009), the acoustic reflectivity of gillnets is weak, resulting in detectability issues for the animals (Au & Jones 1991; Kastelein et al. 2000; Mooney et al. 2004).

The magnitude of gillnet fisheries in Southeast Asia estimated in this chapter (Table 1.2) indicate that these represent a serious threat to regional populations of cetaceans. However, given the limited available bycatch statistics, it was not possible in this overview chapter to make a comprehensive assessment of the bycatch impact on cetacean populations in Southeast Asia.

1.6.2 Cetacean species at risks

Three odontocete species: Irrawaddy dolphins (*Orcaella brevirostris*), Indo-Pacific humpback dolphins (*Sousa chinensis*) and Indo-Pacific finless porpoise (*Neophocaena phocaenoides*) have been identified as some of the species most susceptible and at risk from SSF bycatch (Temple et al. 2021). The three species are widely distributed in Southeast Asia and listed by the IUCN Red List of Threatened Species as Endangered: Irrawaddy dolphin (Minton et al. 2017) and Vulnerable: Indo-Pacific humpback dolphin (Jefferson et al. 2017) and Indo-Pacific finless porpoise (Wang & Reeves 2017). Furthermore, serious concerns have been raised for many subpopulations of Irrawaddy dolphins in Southeast Asian waters (Brownell Jr. et al. 2019). Given their general small subpopulation size (20 – 80 individuals) (Table 1.5) and that all are listed as Critically Endangered by the IUCN Red List of Threatened Species (Brownell Jr. et al. 2019), these subpopulations are at significant risk of extinction mainly due to fisheries bycatch combined with a number of other human threats, including electrofishing, vessel strike, habitat destruction/degradation, dams, and disturbance (Table 1.5) (Brownell Jr. et al. 2019).

Table 1.5 Threats and population status of the Irrawaddy dolphins (*Orcaella brevirostris*) in five Southeast Asian nations. Modified from Brownell Jr. et al. (2019).

Threat	**Country** (Location)				
	Cambodia (Mekong River)	**Indonesia** (Mahakam River)	**Myanmar** (Ayeyarwady River)	**Philippines** (Malampaya Sound)	**Thailand** (Songkhla Lake)
Bycatch	Yes	Yes	Yes	Yes	Yes
Fishing status	Illegal	Legal	Illegal	Illegal	Legal
Electrofishing	Yes	Yes	Yes	No	No
Vessel strike	No	Yes	No	No	No
Habitat loss	Yes	Yes	Yes	No	Yes
Dams	Yes	No	Yes	No	Yes
Disturbance (e.g. aquaculture, pollution and shipping)	No	No	No	No	Yes
Population size	80	76	72	35	20
Year	2015	2016	2004	2012	2004

However, beyond these three species, cetaceans as a whole in Southeast Asia are at risk of extirpation and/or extinction from a combination of anthropogenic factors, including pollution, overfishing/overexploitation, coastal development, hunting, invasive species and climate changes (Davidson et al. 2012; Perrin 2002). Cetaceans and other megafauna are particularly at risk given their life history as an intrinsic factor putting cetaceans under extinction risks, as species with limited or no ability to respond or recover from human impacts (Davidson et al. 2012). The main reason cetaceans are vulnerable to anthropogenic impacts is that they have typically k-selected life histories identified by: slow growth rate, late maturity, and low fecundity (Perrin 2002; Pianka 1970).

1.6.3 Limitation of bycatch assessment

Despite available global cetacean bycatch estimates (Lewison et al. 2014; Read et al. 2006; Reeves et al. 2013), and the fact that hundreds of thousands are likely the number killed each year, these assessments were based on data from and applied to industrial fisheries primarily in mainly high-income regions (e.g. North America and Europe) (Jog et al. 2022). This bias has overlooked the contribution from SSF and subsequently reflects underestimates in the global assessments of cetacean bycatch in terms of volume and distribution (Lewison et al. 2014; Read et al. 2006). There is therefore a need for updated regional and global assessments for cetacean bycatch that includes all fisheries where bycatch occurs (industrial, semi-industrial and small-scale) and applying methods that allow comprehensive assessment to be conducted (Moore et al. 2021a; Wade et al. 2021).

There is an urgent need to obtain bycatch data in Southeast Asia and this could be achieved using a combination of sources, including questionnaire surveys, stranding reports, fisheries landings, onboard vessel recording (using observers and/or remote electronic monitoring) in order to generate the necessary data for assessments of bycatch. Further, research investigating and estimating species distribution, genetic structure, abundance, biology and ecology should also be conducted to facilitate comprehensive impact assessment of bycatch mortality and allow for status conservation assessment, particularly for species that are currently listed as threatened or data deficient by the IUCN Red List of Threatened species.

The current lack of scientific literature on SSF catch and the limited and variable official statistics are some of the main problems preventing current and future comprehensive bycatch assessments. During the implementation of this thesis, I was informed by researchers (personal communication) from the Department of Marine and Coastal Resources (DMCR), Thailand, that cetacean bycatch data may exist in Thailand, and that the DMCR was the holder of these data. However, I contacted the DMCR and the Department of Fisheries (DOF) in search for and requested access to the bycatch data for cetaceans in Thailand, but the response I received was that no authorised entities acknowledged the existence of any bycatch data and neither DMCR or DOF claimed to have responsibility for such data. I also contacted the Thai central, regional and municipal government organisations and asked if they possessed the data, but the responses were the same i.e. all responded they had no knowledge of such data. Hence, research presented in thesis did not have access to any official bycatch data that may or may not exist.

1.6.4 Conclusions

This chapter has provided estimates for the number of SSF vessels for nine countries in Southeast Asia for four fishing gear responsible for marine megafauna, and cetaceans in particular, bycatch mortality based on collation of available FAO data. The chapter further identified some of the information gaps relating to bycatch of cetaceans in Southeast Asian SSF. There are limited systematic and consistent data available for this region. SSF effort were reported and estimated for four gear types: gillnets, longlines, other nets and traps, but there are a number of other gear types used by SSF fishers that may also contribute to cetacean bycatch (Mustika et al. 2021; Suebpala et al. 2017) as demonstrated in Chapter 2 of this thesis.

SSF compose a large majority of the global fisheries (Béné 2006; FAO 2020a; Pauly 2006) with the potential for having significant negative impacts on cetaceans (Basran & Sigurðsson 2021; Brownell Jr. et al. 2019; Mangel et al. 2010; Nelms et al. 2021). Yet, SSF represents a particularly data-poor sector (Komoroske & Lewison 2015), with huge knowledge gaps for data in developing countries in Southeast Asia. Nevertheless, researchers have drawn on community-based social science interviews and survey methods to start addressing this knowledge gap (Kiszka 2012; Moore et al. 2010; Mustika et al. 2021; Temple et al. 2018). Systematic investigations using interviews with local communities are logistically and financially feasible to gather bycatch data in SSF at country-wide scale (Moore et al. 2021a; Wade et al. 2021). Further, interviews also have a great potential to address knowledge gaps (Acebes et al. 2015; Moore et al. 2010; Mustika et al. 2021) of SSF and cetacean bycatch and may provide reliable and comparable data to estimate bycatch rate across regions, species and fishing gear types.

CHAPTER 2

Marine Megafauna Catch in Thai Small-Scale Fisheries

2.1 | Abstract

Catch in small-scale fisheries is a global conservation threat to marine megafauna (rays, sharks, sea turtles, cetaceans and dugon) species and populations. There is currently limited information about marine megafauna catch in Thailand’s small-scale fisheries. This study represents the first independent catch assessment of marine megafauna in Thai small-scale fisheries. Data on catch and fisheries effort across one year (2016 – 2017) were collected from questionnaire-based interviews with 535 fishers in 17 provinces along the Gulf of Thailand and the Andaman Sea from September to December 2017. Catch Per Unit Effort (CPUE) estimates were generated for each megafauna group by fishery gear type. Annual estimated catch for each megafauna group was extrapolated using Thai official fisheries statistics. The results reveal mean annual estimated catches of 5,662,024 (95% CI: 4,097,779 – 7,817,707) rays, 457,864 (95% CI: 192,352 – 969,166) sharks, 2,400 (95% CI: 1,610 – 3,537) sea turtles, 790 (95% CI: 519 – 1,167) cetaceans and 72 (95% CI: 19 – 194) dugongs in Thai small-scale fisheries. In the Gulf of Thailand: crab gillnets had the highest CPUEs for rays, sharks and cetaceans; pound nets for sea turtles; and ray gillnets for dugong. In the Andaman Sea: crab gillnets also had the highest CPUEs for rays and sharks; squid trammel nets for sea turtles; and shrimp trammel nets for cetaceans and dugong. Further, the annual estimated catches are considered as minimum estimates as a number of fishing gears reported to catch megafauna in the questionnaire survey had to be excluded from the extrapolations as they did not appear in the official fisheries statistics. The results highlight the need for further comprehensive

assessment of marine megafauna catch in Thai small-scale fisheries to facilitate evidence-based management of these vulnerable species.

2.2 | Introduction

Marine megafauna (cetaceans, dugongs, sea turtles, and elasmobranchs i.e. rays and sharks) are threatened by a range of anthropogenic activities impacting either the species and/or their habitats, including: fisheries catch (Burgess et al. 2018; Dulvy et al. 2014; Reeves et al. 2013), habitat destruction (Balladares & Barrios-Garrido 2021; Dulvy et al. 2021; Karczmarski et al. 2017; Muir et al. 2003) and tourism (Christiansen & Lusseau 2014; Hanafy et al. 2006; Healy et al. 2020; Schofield et al. 2015). Fisheries catch and bycatch (hereafter "catch") represent the greatest threat to the marine megafauna (Dulvy et al. 2021; Lewison et al. 2014; Read et al. 2006) currently threatening a number of populations and species with extirpation and extinction (Brownell Jr. et al. 2019). Thai large-scale/industrial/commercial fisheries catch have been recognised for their detrimental impacts on marine megafauna (Krajangdara 2014; Teh et al. 2015a), however, impact from catch in small-scale/artisanal fisheries (SSF) have received little attention to date.

Thai SSF are likely to be an important contributor to the catch of marine megafauna in Thailand. There was an average of 56,001 SFF vessels operating in the Gulf of Thailand and the Andaman Sea between 2005 and 2018 (FAO 2020a). The average annual estimated marine catch in the SSF between 2015 – 2017 was 84,075 tons in the Gulf of Thailand (9% of all catches in the Gulf of Thailand) and 76,996 tons in the Andaman Sea (20% of all catches in the Andaman Sea) (De Leon & Derrick 2020). Thai SSF are primarily conducted for local subsistence and local commercial purposes with < 10 tons of vessel capacity, and they use a broad range of hand-operated fishing gears known to impact marine megafauna including gillnets and longlines (Lymer et al. 2008; Pimoljinda 2002). According to the Thai official fisheries statistics, the dominant SSF gears in the Gulf of Thailand are crab gillnets (29% of all gears used), other gillnets (25%) and squid falling nets (18%), whereas in the Andaman Sea other gillnets dominate (39% of all gears used) followed by shrimp trammel nets (24%) and crab gillnets (21%) (DOF 2016). SSF are economically essential as sources of income and livelihood for Thai coastal communities (Teh et al. 2015a).

Depending on both geographical area and fishery, marine megafauna may be considered as either target or non-target species in Thai SSF, and most have some commercial value as consumable and marketable materials (Krajangdara 2014; Krajangdara 2017). Elasmobranchs are caught by a wide range of SSF gears including gillnets, hook, lines and traps (Krajangdara 2017). Their fins and meat are commercially valuable and are traded among communities or sold to restaurants (Krajangdara 2014). Elasmobranch skins are also sold for leather-wear industries (Krajangdara 2014). In contrast, intentional catches of cetaceans, dugongs (*Dugong dugon*) and sea turtles are prohibited (GG 1992; GG 2014; GG 2019). However, catches may be a significant cause for concern for cetaceans as indicated by the 550+ recorded cases of strandings in Thailand during the past three decades, where fishing gear entanglement has been identified as one of the likely causes of mortality (Adulyanukosol et al. 2012a).

An understanding of the current situation with regards to megafauna catch in Thailand is a key to assess whether current exploitation of the marine environment is sustainable. As apex predators and mega-grazers, marine megafauna often have a key role for the stability and productivity of marine ecosystems (Heithaus et al. 2008; Kiszka et al. 2015; Tavares et al. 2019). Hence, the decline, extirpation or extinction of megafauna species risk destabilising and/or restructuring ecosystems through causing trophic cascade (Pinnegar et al. 2000). There are 82 rays, 76 sharks, 27 cetaceans, five sea turtles and one sirenian species known to occur in Thai waters (Adulyanukosol et al. 2014; Krajangdara 2017). Despite the relatively high diversity of marine megafauna in Thailand, there is little available information on species abundance and fisheries interactions. Basic data on SSF catch and composition, catch levels and effort for the different gear used are essential for assessment and monitoring of megafauna catch and fisheries management.

This study aims to provide the first independent assessment of marine megafauna catch in Thai SSF by combining catch composition and Catch Per Unit Effort (CPUE) derived from interviews of SSF fishers in the Gulf of Thailand and the Andaman Sea with official fisheries effort statistics. The resultant estimated catch and compositional data from this study will provide an evidence-base for prioritising future research and assessment of Thai SSF.

2.3 | Methods

2.3.1 Study sites

Face-to-face questionnaire-based interviews (n = 535) were conducted by the author in Thai with fishers during September to December 2017 at 32 fishing communities across 17 provinces (Gulf of Thailand: n = 335 and Andaman Sea: n = 200) (Figure 2.1). In each fishing community, 30 – 35 randomly-selected fishers were interviewed (normally the captain and ensuring only one respondent per vessel). Seven out of the total available 24 provinces were excluded from the interviews due to low fishing effort and safety risk from insurgency in some provinces. Before conducting the interviews, the community/village headman was contacted in each community to ask for permission to conduct the interviews. On the day of the interviews, the author was escorted by the community/village headman, or the headman’s assistant, to access the community areas, where the interviews were conducted.

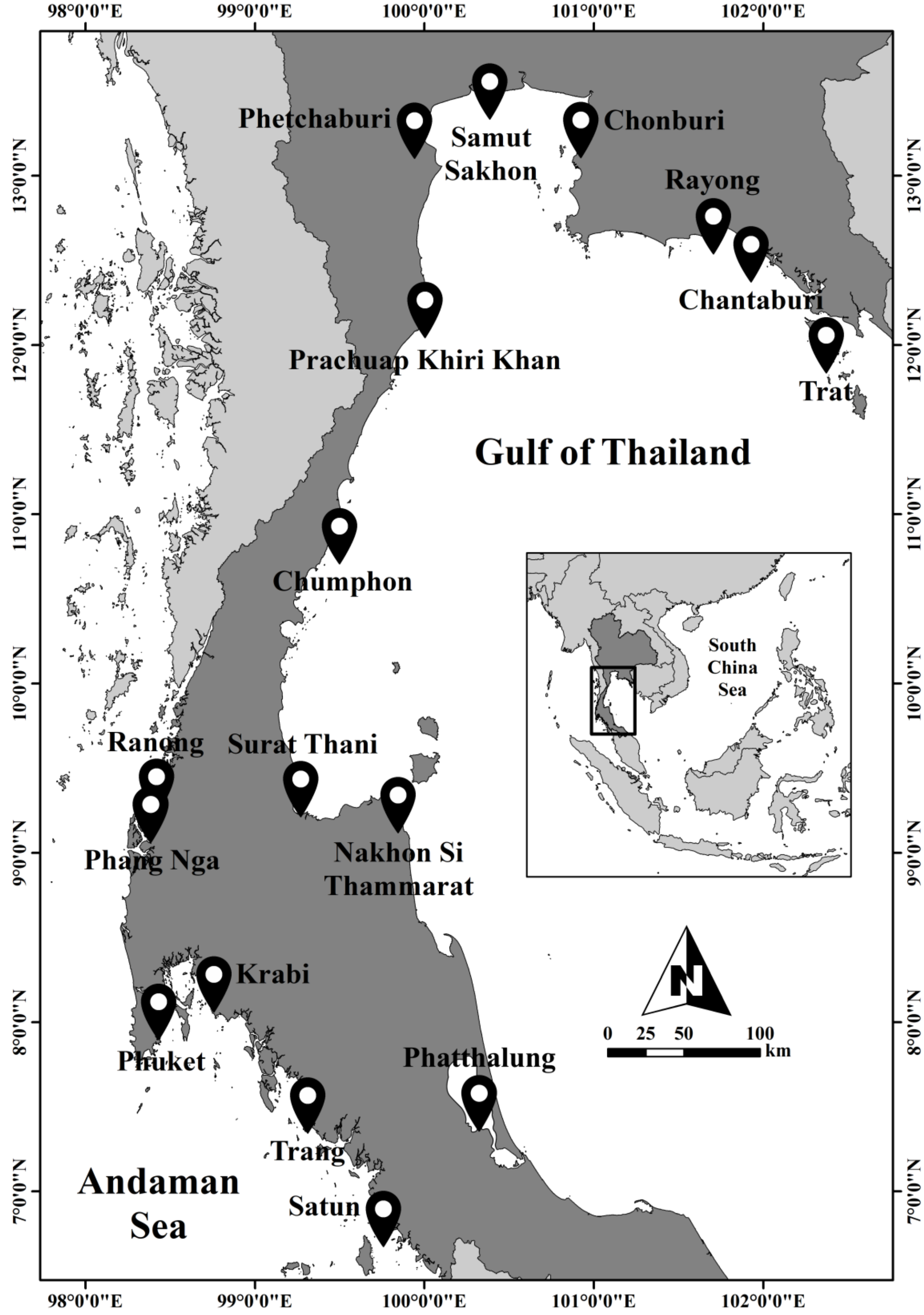


Figure 2.1 Location of the sites in the 17 provinces where questionnaire interviews were conducted to assess marine megafauna catch in the small-scale fisheries in the Gulf of Thailand and the Andaman Sea between September 2016 and December 2017

2.3.2 Questionnaire interview and data

The questionnaire (Appendix 1) was adapted from previously used protocols (Alfaro-Shigueto et al. 2018; Moore et al. 2010; Temple et al. 2020) and covered fishing activities conducted during the preceding year (12 consecutive months) between September 2016 and December 2017. The questionnaire included two sections: (1) fishing effort and (2) marine megafauna catches. The fishing effort data included: gear type (Table 2.1) and configuration, effort (number of gears used per fishing day and number of days fished per month/year), fishing location (including km from shore), and target species. The marine megafauna catch data included: species group caught, catch number of each species group, month of catch, gear used, location, and utilisation of catch.

A marine megafauna species identification photobook (Appendix 2), adapted from Adulyanukosol et al. (2014) and Krajangdara (2017), was used during the interviews to help confirm the species identity of catches. Where possible catches were resolved to species or genus levels, in some cases genuses' were grouped where identification before the family level was difficult or inconsistent (Table 2.2). The interviews took 5 – 10 minutes depending on how the fishers reported their catches and fishing activities. During the interviews, the fishers were offered the chance not to answer any questions and they were able to end the interview at any time if they so wished. The interviews were strictly confidential to protect fishers' identities. The gears declared by the fishers were classified into the 21 categories (Table 2.1) used in the Thai fishing vessels statistics in 2014 (DOF 2016) (Appendix 3).

Table 2.1 Small-scale fishing gears used by 535 fishers in Thailand between September 2016 and December 2017 as reported during questionnaire interviews conducted between September and December 2017. (*) indicates the gears reported in the Thai fishing vessels statistics (DOF 2016).

Gear	Gear name
CG*	Crab gillnets
CT	Crab traps
FBG	Fish bottom-set gillnets
FDG	Fish drift gillnets
FRR	Fishing rods and reels
HL	Handlines
LL*	Longlines
MG*	Mackerel gillnets
PDN	Pound nets/bamboo stake traps
PN*	Push nets
RG	Ray gillnets
SQFN*	Squid falling nets
SQJ	Squid jigs
SQT	Squid traps
SQTN*	Squid trammel nets
STN*	Shrimp trammel nets
XG*	Other gillnets
XLN*	Other lift nets
XN*	Other nets
XT	Other traps
XX*	Other gears

2.3.3 Data analysis

Mean Catch Per Unit Effort (CPUE) was calculated for each species group by gear type and province using the data from the questionnaire interviews. CPUEs were then elevated to the regional and national level using total fisheries effort (number of vessels using respective gear in each region: Gulf of Thailand and Andaman Sea) from the official Thai fishing vessels statistics in 2014 (DOF 2016) (Appendix 3).

Table 2.2 Marine megafauna species groups reported as catch by 535 fishers in Thailand between September 2016 and December 2017 from the questionnaire interviews conducted between September and December 2017

Marine megafauna species group	Scientific name
Rays	
Butterfly rays	*Gymnura* spp.
Devil rays	*Mobula* spp.
Eagle rays	*Aetobatus* spp. *and Aetomylaeus* spp.
Guitarfish	*Glaucostegus* spp.
Numbfish	*Narcine* spp.
Sawfish	*Pristis* spp.
Small sting/whiprays	*Brevitrygon* spp.
Sting/whiprays	*Hemitrygon* spp., *Himantura* spp., *Maculabatis* spp. *and Pastinachus* spp.
Wedgefish	*Rhynchobatus* spp.
Sharks	
Bamboo sharks	*Chiloscyllium* spp.
Gummy sharks	*Mustelus* spp.
Hammerhead sharks	*Sphyrna* spp.
Nurse shark	*Nebrius ferrugineus*
Reef sharks	*Carcharhinus* spp.
Sand tiger shark	*Carcharias taurus*
Thresher sharks	*Alopias* spp.
Tiger shark	*Galeocerdo cuvier*
Whale shark	*Rhincodon typus*
Zebra shark	*Stegostoma fasciatum*
Sea turtles	
Green turtle	*Chelonia mydas*
Hawksbill turtle	*Eretmochelys imbricata*
Olive Ridley turtle	*Lepidochelys olivacea*
Cetaceans	
Indo-Pacific bottlenose dolphin	*Tursiops aduncus*
Indo-Pacific finless porpoise	*Neophocaena phocaenoides*
Indo-Pacific humpback dolphin	*Sousa chinensis*
Irrawaddy dolphin	*Orcaella brevirostris*
Dugong	
Dugong	*Dugong dugon*

2.3.3.1 Catch Per Unit Effort (CPUE)

Mean CPUE was calculated as the number of animals caught per vessel per year for each marine megafauna group, by fishing gear type and province. CPUEs by gear for each province were calculated using the formula:

$$\mathrm{CPUE_P} = \sum_{i=1}^{n} \mathrm{C_i} \, / \, \mathrm{E_i}$$

where $\mathrm{CPUE_P}$ = CPUE by gear type generated from each province; $\mathrm{C_i}$ = total number of animals caught per year using the corresponding fishing gear type, as reported by the respondents to the questionnaire interviews; and $\mathrm{E_i}$ = number of interviewees using the corresponding fishing gear type. A percentile bootstrap procedure (IBM SPSS Statistics 25) was used to determine the asymmetric 95% confidence interval (CI) for each CPUE value.

CPUEs were calculated separately for the two regions (Gulf of Thailand and Andaman Sea). Regional weighted CPUEs were calculated using the formula:

$$\mathrm{CPUE_R} = \sum_{i=1}^{n} \left(\mathrm{CPUE_P} \times \frac{\mathrm{E_P}}{\mathrm{E_R}} \right)$$

where $\mathrm{CPUE_R}$ = catch per year per vessel at regional level; $\mathrm{E_P}$ = total number of fishing vessels using the corresponding fishing gear type in each province as reported by the Thai fisheries statistics (DOF 2016); $\mathrm{E_R}$ = total number of fishing vessels using the corresponding fishing gear type in each sea region (Gulf of Thailand/Andaman Sea) as reported by the Thai fisheries statistics (DOF 2016). Regional asymmetrical 95% CIs corresponding to their regional weighted CPUEs were calculated using the formulas:

$$\mathrm{L_R} = \mathrm{CPUE_R} - \sqrt{\sum_{i=1}^{n} \left((\mathrm{CPUE_P} - \mathrm{L_P}) \times \frac{\mathrm{E_P}}{\mathrm{E_R}} \right)^2}$$

$$U_R = CPUE_R + \sqrt{\sum_{i=1}^{n}\left((U_P - CPUE_P) \times \frac{E_P}{E_R}\right)^2}$$

where L_R = lower limit of $CPUE_R$; U_R = upper limit of $CPUE_R$; L_P = lower limit corresponding to the $CPUE_P$; and U_P = upper limit corresponding to the $CPUE_P$.

2.3.3.2 Annual estimated catch

Annual estimated catch was extrapolated for each sea region by multiplying the calculated $CPUE_R$ by the total number of fishing vessels using the corresponding gear in the Gulf of Thailand and the Andaman Sea, respectively as reported in the Thai fishing vessels statistics (DOF 2016) (Appendix 3). Annual estimated catches and corresponding 95% CIs were calculated as:

$$AEC = CPUE_R \times E_R$$

$$CI_{AEC} = CI_R \times E_R$$

where AEC = annual estimated catch; CI_{AEC} = 95% confidence interval corresponding to the AEC; and CI_R = 95% confidence interval corresponding to the $CPUE_R$.

2.3.3.3 Comparison of CPUEs among fishing gears

A Generalised Linear Model (GLM) was used to investigate potential variability of megafauna group reported CPUEs among fishing gears. Since the fishers reported their catches by the unit "number of animals caught per vessel per year", each reported catch represented a separate CPUE. The negative binomial family was fit to account for the overdispersion of the catch data.

The Huber-White standard errors (Huber 1967; White 1980) approach was used to allow the fitting of a model that does contain heteroscedastic residuals, and the Bonferroni correction (Bonferroni 1936) was applied in the post hoc tests to adjust significance levels for multiple tests to avoid Type I error. Post hoc tests (pairwise comparisons) (Shiraishi et al. 2019) were conducted to investigate if there were significant differences in the CPUEs between gears for each megafauna group using Estimated Marginal Means (EMM) as a measure. All statistical tests were performed using IBM SPSS Statistics 25.

2.3.4 Ethical approval

This study received ethical approval from the Newcastle University Ethics Committee (reference number: 15906/2016).

2.4 | Results

2.4.1 Reported catches

The annual marine megafauna catches in 2016 – 2017 as reported by respondents to the questionnaire were 419,821 rays, 28,920 sharks, 269 sea turtles, 47 cetaceans and 6 dugongs, of which 231,992 rays, 20,084 sharks, 246 sea turtles, 44 cetaceans and 5 dugongs, were reported for the Gulf of Thailand and 187,642 rays, 8,836 sharks, 23 sea turtles, 3 cetaceans and 1 dugong in the Andaman Sea.

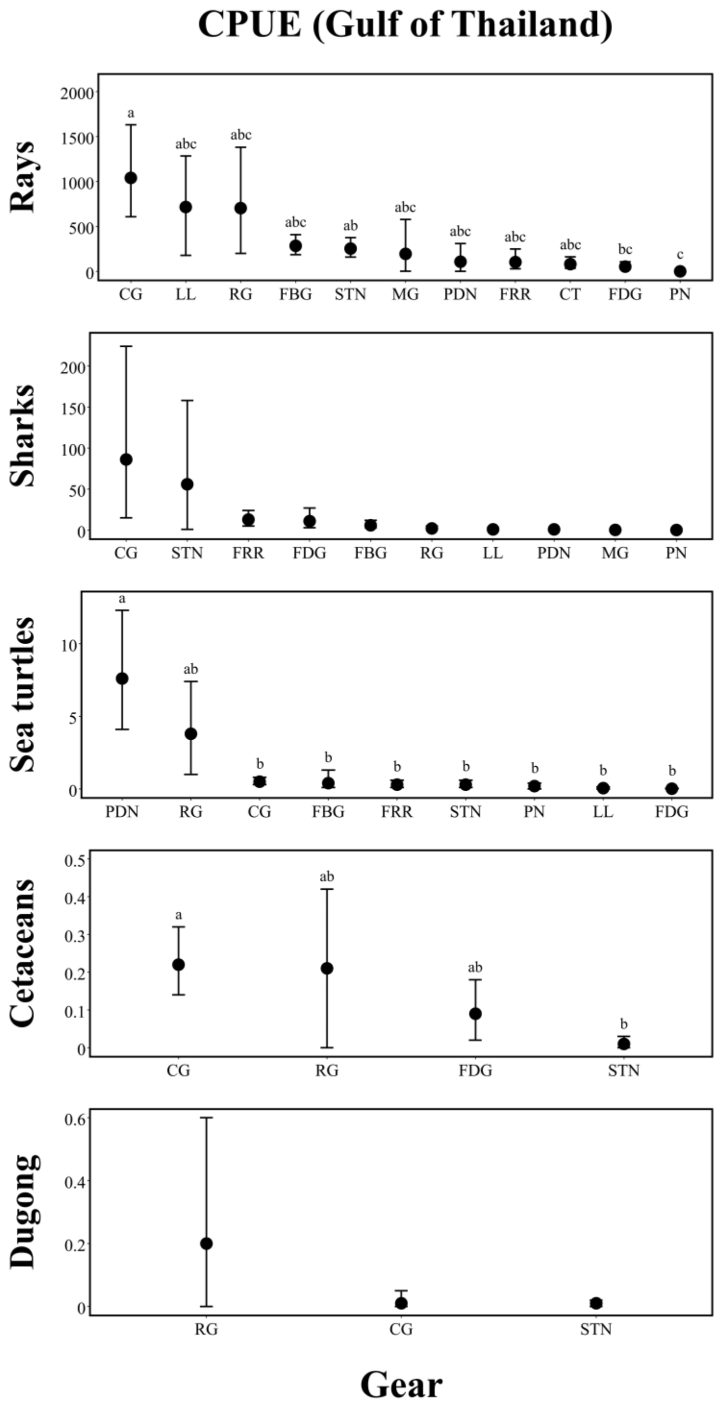


Figure 2.2 Mean CPUE (number of animals caught per vessel per year) of marine megafauna in small-scale fisheries based on questionnaire interviews from 11 provinces in the Gulf of Thailand (n = 335) and 6 provinces in the Andaman Sea (n = 200) covering the fishing activity over 12 months during the period between September 2016 and December 2017. Error bars represent asymmetric 95% confidence intervals. Different letters above the error bars indicate the gear pairs with significant differences in Estimated Marginal Means (EMM) reported CPUEs ($p < 0.05$). CG = crab gillnets, CT = crab traps, FBG = fish bottom-set gillnets, FDG = fish drift gillnets, FRR = fishing rods and reels, LL = longlines, MG = mackerel gillnets, PDN = pound nets, PN = push nets, RG = ray gillnets, STN = shrimp trammel nets. For more details, see Table 1.7.

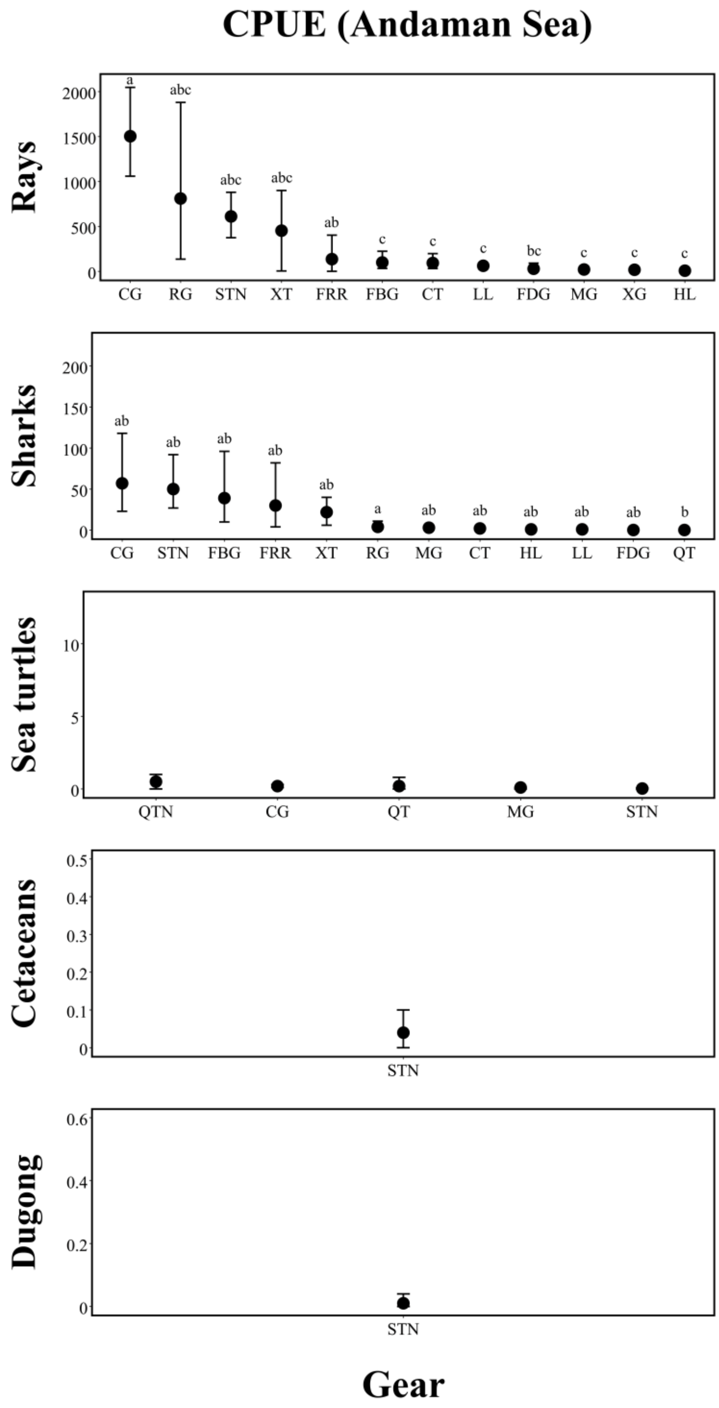


Figure 2.3 Mean CPUE (number of animals caught per vessel per year) of marine megafauna in small-scale fisheries based on questionnaire interviews from 11 provinces in the Gulf of Thailand (n = 335) and 6 provinces in the Andaman Sea (n = 200) covering the fishing activity over 12 months during the period between September 2016 and December 2017. Error bars represent asymmetric 95% confidence intervals. Different letters above the error bars indicate the gear pairs with significant differences in Estimated Marginal Means (EMM) reported CPUEs ($p < 0.05$). CG = crab gillnets, CT = crab traps, FBG = fish bottom-set gillnets, FDG = fish drift gillnets, FRR = fishing rods and reels, HL = handlines, LL = longlines, MG = mackerel gillnets, QT = squid traps, QTN = squid trammel nets, RG = ray gillnets, STN = shrimp trammel nets, XG = other gillnets and XT = other traps. For more details, see Table 1.7.

Table 2.3 Mean CPUE (number of animals caught per vessel per year ± 95% CI) of marine megafauna in small-scale fisheries based on questionnaire interviews from 11 provinces in the Gulf of Thailand (n = 335) and 6 provinces in the Andaman Sea (n = 200) covering the fishing activity over 12 months during the period between September 2016 and December 2017. (-) indicates no reported gear efforts. (CG = crab gillnets, CT = crab traps, FBG = fish bottom-set gillnets, FDG = fish drift gillnets, FRR = fishing rods and reels, HL = handlines, LL = longlines, MG = mackerel gillnets, PDN = pound nets, PN = push nets, QT = squid traps, QTN = squid trammel nets, RG = ray gillnets, STN = shrimp trammel nets, XG = other gillnets and XT = other traps)

Marine megafauna	**Gear**	**Gulf of Thailand**		**Andaman Sea**	
		CPUE	**95% CI**	**CPUE**	**95% CI**
Rays	CG	1040	(608 – 1631)	1504	(1059 – 2047)
	CT	80	(34 – 162)	94	(32 – 198)
	FBG	285	(186 – 409)	100	(33 – 224)
	FDG	53	(22 – 107)	30	(1 – 92)
	FRR	104	(29 – 249)	136	(1 – 403)
	HL	-	-	8	(0 – 24)
	LL	717	(178 – 1284)	63	(25 – 98)
	MG	195	(2 – 578)	22	(4 – 58)
	PDN	107	(1 – 310)	-	-
	PN	1	(0 – 2)	-	-
	RG	703	(200 – 1381)	811	(136 – 1880)
	STN	254	(159 – 376)	611	(375 – 880)
	XG	-	-	18	(3 – 35)
	XT	-	-	453	(5 – 900)
Sharks	CG	86	(15 – 224)	57	(23 – 118)
	CT	-	-	2	(1 – 5)
	FBG	6	(3 – 12)	39	(10 – 96)
	FDG	11	(3 – 27)	0.2	(0.0 – 0.4)
	FRR	13	(5 – 24)	30	(4 – 82)
	HL	-	-	1	(0 – 3)
	LL	1	(0 – 3)	1	(0 – 2)
	MG	0.3	(0.0 – 0.9)	3	(1 – 4)
	PDN	1	(0 – 2)	-	-
	PN	0.2	(0.0 – 0.4)	-	-
	QT	-	-	0.2	(0.0 – 0.6)
	RG	2	(1 – 5)	4	(1 – 11)
	STN	56	(1 – 158)	50	(27 – 92)
	XT	-	-	22	(6 – 40)
Sea turtles	CG	0.5	(0.3 – 0.8)	0.2	(0.1 – 0.3)
	FBG	0.4	(0.1 – 1.3)	-	-
	FDG	0.02	(0.01 – 0.05)	-	-
	FRR	0.3	(0.1 – 0.6)	-	-
	LL	0.05	(0.00 – 0.14)	-	-
	MG	-	-	0.1	(0.0 – 0.1)
	PDN	7.6	(4.1 – 12.3)	-	-
	PN	0.2	(0.0 – 0.4)	-	-
	QT	-	-	0.2	(0.0 – 0.8)
	QTN	-	-	0.5	(0.0 – 1.0)
	RG	3.8	(1.0 – 7.4)	-	-
	STN	0.3	(0.1 – 0.6)	0.03	(0.00 – 0.07)
Cetaceans	CG	0.22	(0.14 – 0.32)	-	-
	FDG	0.09	(0.02 – 0.18)	-	-
	RG	0.21	(0.00 – 0.42)	-	-
	STN	0.01	(0.00 – 0.03)	0.04	(0.00 – 0.10)
Dugong	CG	0.01	(0.00 – 0.05)	-	-
	RG	0.2	(0.0 – 0.6)	-	-
	STN	0.01	(0.00 – 0.02)	0.01	(0.00 – 0.04)

2.4.2 Catch Per Unit Effort (CPUE)

In the Gulf of Thailand, crab gillnets had the highest CPUE for rays [1,040 (95% CI: 608 – 1,631)], sharks [86 (95% CI: 15 – 224)] and cetaceans [0.22 (95% CI: 0.14 – 0.32)], whilst pound nets had the highest CPUE for sea turtles [7.6 (95% CI: 4.1 – 12.3)] and ray gillnets for dugong [0.2 (95% CI: 0.0 – 0.6)] (Figure 2.2 and Table 2.3). In the Andaman Sea, crab gillnets also had the highest CPUE for rays [1,504 (95% CI: 1,059 – 2,047)] and sharks [57 (95% CI: 23 – 118)], while squid trammel nets had the highest CPUE for sea turtles [0.5 (95% CI: 0.0 – 1.0)]. Shrimp trammel nets were the only gear that caught cetaceans and dugong with CPUEs of 0.04 (95% CI: 0.00 – 0.10) and 0.01 (95% CI: 0.00 – 0.04), respectively (Figure 2.3 and Table 2.3).

2.4.3 Annual estimated catches

The annual estimated catches for Thai SSF were: 5,662,024 (95% CI: 4,097,779 – 7,817,707) rays, 457,864 (95% CI: 192,352 – 969,166) sharks, 2,400 (95% CI: 1,610 – 3,537) sea turtles, 790 (95% CI: 519 – 1,167) cetaceans and 72 (95% CI: 19 – 194) dugongs based on catches declared between September 2016 and December 2017 (Table 2.4). In the Gulf of Thailand, the annual estimated catches of rays, sharks, sea turtles, cetaceans and dugong were 4,364,690 (95% CI: 2,829,717 – 6,489,806), 391,711 (95% CI: 127,354 – 901,025), 2,279 (95% CI: 1,491 – 3,413), 765 (95% CI: 495 – 1,139) and 64 (95% CI: 11 – 184), respectively. In the Andaman Sea, the annual estimated catches of rays, sharks, sea turtles, cetaceans and dugong were 1,297,333 (95% CI: 996,140 – 1,659,074), 66,153 (95% CI: 41,415 – 111,191), 121 (95% CI: 69 – 190), 25 (95% CI: 0 – 65) and 8 (95% CI: 0 – 28), respectively (Table 2.4).

Table 2.4 Annual estimated catch (AEC ± 95% CI) of marine megafauna per gear type in small-scale fisheries in the Gulf of Thailand and the Andaman Sea during the period between September 2016 and December 2017. Only gear types for which official Thai fishing vessels statistics were available are included (DOF 2016). (-) indicates no reported gear efforts. (CG = crab gillnets, LL = longlines, MG = mackerel gillnets, PN = push nets, STN = shrimp trammel nets and XG = other gillnets; Grand total = GOT + AS)

Marine megafauna	**Gear**	**Gulf of Thailand (GOT)**		**Andaman Sea (AS)**	
		AEC	**95% CI**	**AEC**	**95% CI**
Rays	CG	3,626,897	(2,119,886 – 5,686,797)	872,231	(613,976 – 1,187,379)
	LL	78,113	(19,399 – 139,997)	3,603	(1,449 – 5,572)
	MG	242,377	(2,638 – 720,363)	2,299	(421 – 6,020)
	PN	185	(28 – 397)	-	-
	STN	417,118	(261,747 – 618,677)	400,058	(245,943 – 576,639)
	XG	-	-	19,143	(2,948 – 37,571)
	Total	4,364,690	(2,829,717 – 6,489,806)	1,297,333	(996,140 – 1,659,074)
	Grand total	**5,662,024**	**(4,097,779 – 7,817,707)**		
Sharks	CG	299,501	(51,030 – 780,285)	32,793	(13,494 – 68,459)
	LL	97	(0 – 324)	56	(13 – 90)
	MG	374	(0 – 1,121)	267	(107 – 409)
	PN	28	(0 – 67)	-	-
	STN	91,711	(1,450 – 259,779)	33,038	(17,560 – 60,538)
	Total	391,711	(127,354 – 901,025)	66,153	(41,415 – 111,191)
	Grand total	**457,864**	**(192,352 – 969,166)**		
Sea turtles	CG	1,815	(1,098 – 2,759)	98	(49 – 160)
	LL	5	(0 – 16)	-	-
	MG	-	-	6	(0 – 14)
	PN	32	(0 – 67)	-	-
	STN	428	(102 – 1,055)	18	(0 – 44)
	Total	2,279	(1,491 – 3,413)	121	(69 – 190)
	Grand total	**2,400**	**(1,610 – 3,537)**		
Cetaceans	CG	751	(482 – 1,124)	-	-
	STN	14	(0 – 46)	25	(0 – 65)
	Total	765	(495 – 1,139)	25	(0 – 65)
	Grand total	**790**	**(519 – 1,167)**		
Dugong	CG	52	(0 – 169)	-	-
	STN	12	(0 – 38)	8	(0 – 28)
	Total	64	11 – 184)	8	(0 – 28)
	Grand total	**72**	**(19 – 194)**		

Crab gillnets generated the highest annual estimated catches for all marine megafauna groups in the Gulf of Thailand (Table 2.4) with 83%, 77%, 80%, 98% and 81% of catch contributions for rays, sharks, sea turtles, cetaceans and dugong, respectively (Figure 2.4). In the Andaman Sea, shrimp trammel nets generated the highest annual estimated catches for sharks (50%), cetaceans (100%) and dugong (100%), whereas crab gillnets had the highest annual estimated catches for rays (67%) and sea turtles (81%) (Figure 2.4 and Table 2.4). The annual estimated catches of all marine megafauna corresponding to the specific gear are presented in Figure 2.4 and Table 2.4.

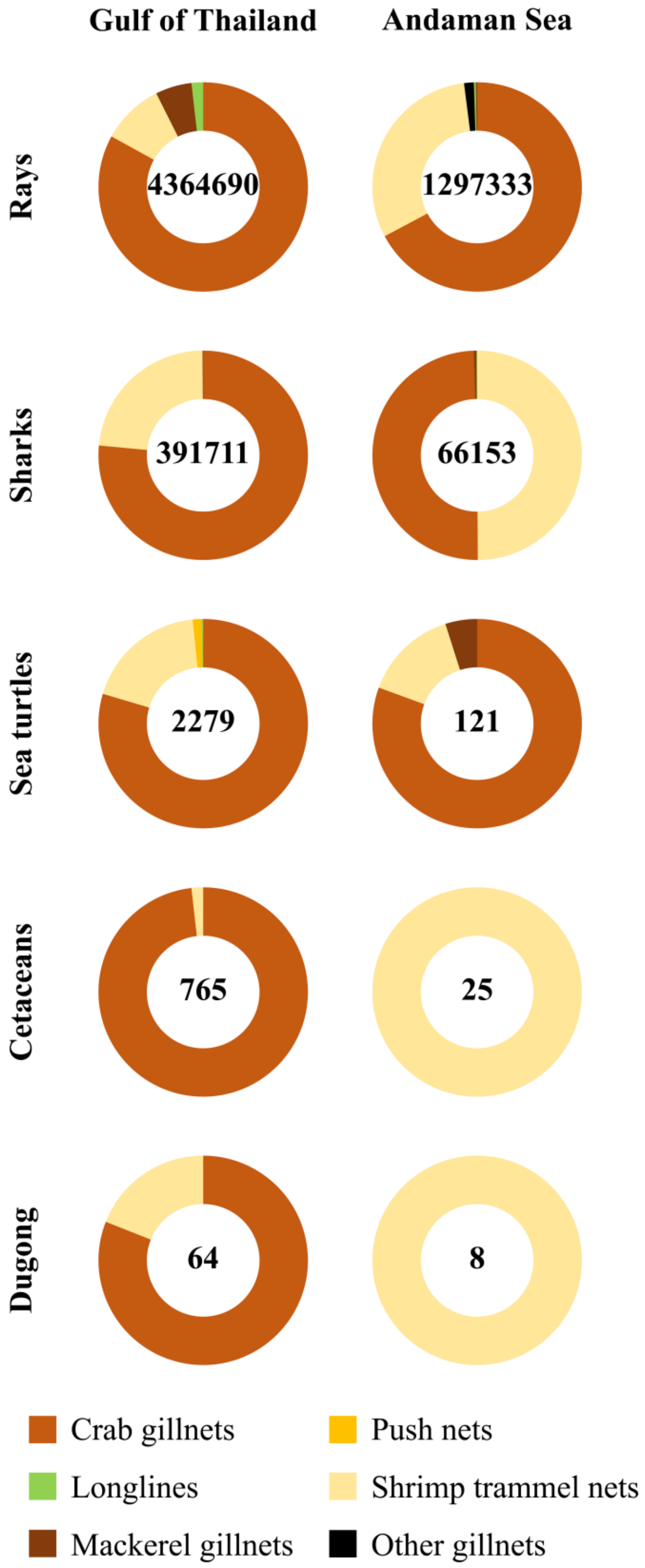


Figure 2.4 Percentage of catch contribution by fishing gear to annual estimated marine megafauna catch in small-scale fisheries in the Gulf of Thailand and the Andaman Sea during the period between September 2016 and December 2017. Annual estimated catch is displayed in the centre of each chart.

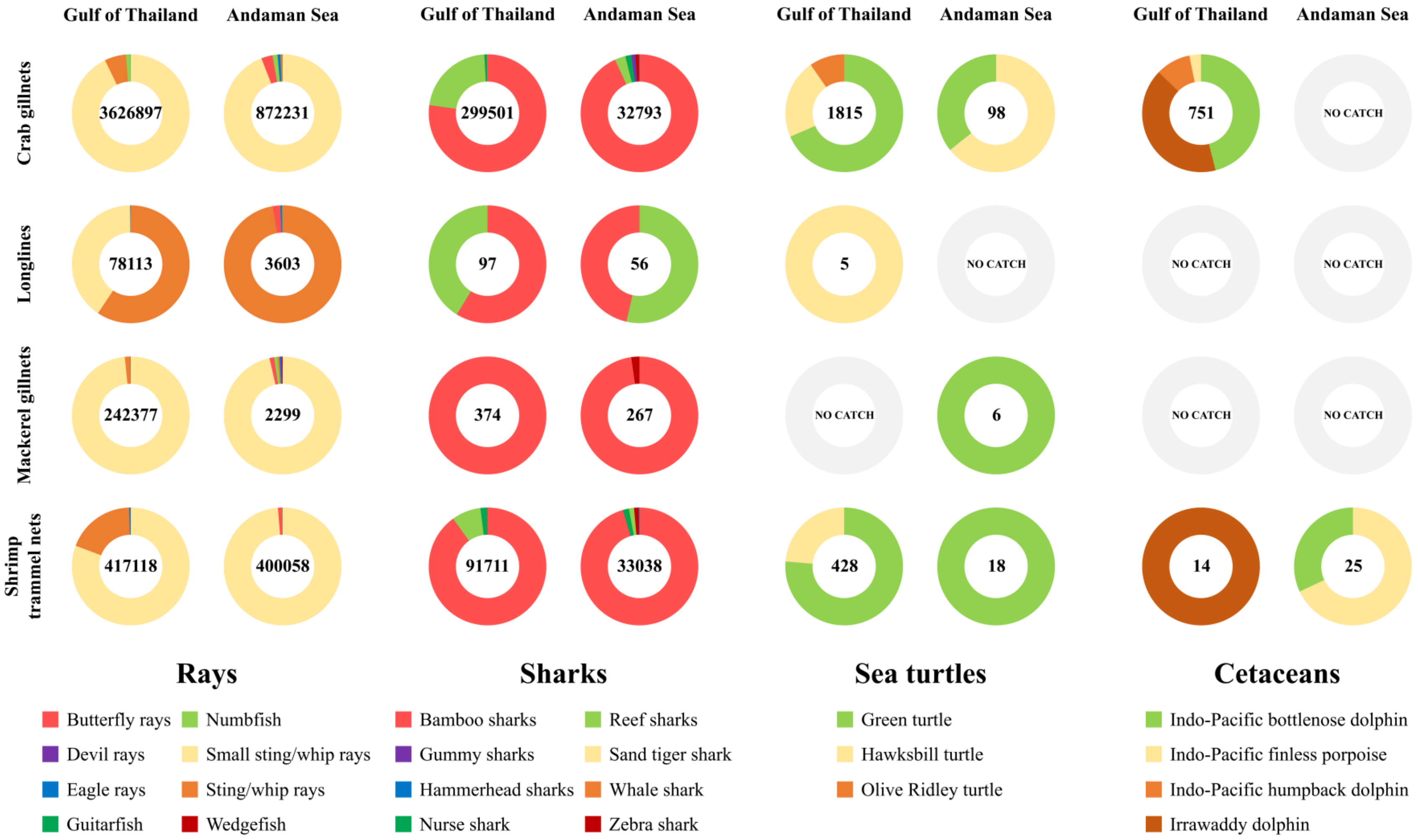


Figure 2.5 Percentage of catch contribution by fishing gear and species group to annual estimated marine megafauna catches in small-scale fisheries in the Gulf of Thailand and the Andaman Sea during the period between September 2016 and December 2017. Annual estimated catch is displayed in the centre of each chart.

Table 2.5 Annual estimated catch (AEC ± 95% CI) per marine megafauna based on species group in small-scale fisheries in the Gulf of Thailand and the Andaman Sea during the period between September 2016 and December 2017. (-) indicates no reported catch.

Marine megafauna species group	Gulf of Thailand		Andaman Sea	
	AEC	**95% CI**	**AEC**	**95% CI**
Rays				
Butterfly rays	-	-	38513	(28233 – 50731)
Devil rays	-	-	5	(1 – 14)
Eagle rays	3966	(2902 – 5410)	7582	(5508 – 10110)
Guitarfish	35	(20 – 54)	475	(334 – 646)
Numbfish	46151	(26975 – 72362)	12331	(8740 – 16713)
Small sting/whip rays	3972401	(2548463 – 5947778)	1218089	(931326 – 1562156)
Sting/whip rays	342080	(242478 – 474307)	20316	(10521 – 31389)
Wedgefish	58	(34 – 90)	21	(15 – 31)
Sharks				
Bamboo sharks	314297	(105918 – 715228)	62380	(39107 – 104732)
Gummy sharks	-	-	363	(149 – 758)
Hammerhead sharks	-	-	90	(57 – 150)
Nurse shark	3949	(1444 – 8720)	1088	(679 – 1831)
Reef sharks	72985	(18099 – 179120)	1456	(847 – 2576)
Sand tiger shark	211	(54 – 356)	-	-
Whale shark	46	(16 – 102)	-	-
Zebra shark	222	(80 – 495)	776	(492 – 1290)
Sea turtles				
Green turtle	1590	(1039 – 2395)	58	(33 – 94)
Hawksbill turtle	514	(339 – 768)	63	(31 – 103)
Olive Ridley turtle	175	(106 – 266)	-	-
Cetaceans				
Indo-Pacific bottlenose dolphin	346	(222 – 518)	8	(0 – 22)
Indo-Pacific finless porpoise	24	(15 – 36)	17	(0 – 43)
Indo-Pacific humpback dolphin	72	(46 – 107)	-	-
Irrawaddy dolphin	324	(212 – 481)	-	-
Dugong				
Dugong	64	(11 – 184)	8	(0 – 28)

The species groups in each megafauna group that had the highest annual estimated catch in the Gulf of Thailand were small sting/whip rays (*Brevitrygon* spp.) (91%), bamboo sharks (*Chiloscyllium* spp.) (80%), green turtle (*Chelonia mydas*) (70%) and Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) (45%), whilst they were small sting/whip rays (94%), bamboo sharks (94%), hawksbill turtle (*Eretmochelys imbricata*) (52%) and Indo-Pacific finless porpoise (*Neophocaena phocaenoides*) (67%) in the Andaman Sea (Figure 2.5 and Table 2.5). The annual estimated catches for all marine megafauna species groups and the catch corresponding to specific gear are presented in Figure 2.5 and Table 2.5.

Table 2.6 Outputs of Generalized Linear Model (GLM) investigating significant ($p < 0.05$) variability of reported CPUEs (number of animals caught per vessel per year) in megafauna groups among fishing gears in small-scale fisheries in the Gulf of Thailand and the Andaman Sea during the period between September 2016 and December 2017. (CG = crab gillnets, FDG = fish drift gillnets, FRR = fishing rods and reels, PDN = pound nets, RG = ray gillnets and STN = shrimp trammel nets).

Gulf of Thailand

Marine megafauna	**Parameter**	**B**	**95% CI**	**SE**	χ^2	**df**	***p*-value**
Rays	(Intercept)	5.21	(4.68 – 5.75)	0.27	361.44	1	< 0.001
	CG	1.11	(0.38 – 1.83)	0.37	8.98	1	0.003
	RG	1.52	(0.47 – 2.58)	0.54	7.96	1	0.005
Sea turtles	(Intercept)	-1.56	(-2.92 – -0.20)	0.69	5.07	1	0.024
	PDN	3.59	(2.14 – 5.05)	0.74	23.31	1	< 0.001
	RG	3.00	(1.24 – 4.76)	0.90	11.17	1	0.001
Dolphins	(Intercept)	-4.79	(-6.74 – -2.84)	1.00	23.11	1	< 0.001
	CG	3.12	(1.13 – 5.11)	1.02	9.43	1	0.002
	RG	3.18	(0.87 – 5.49)	1.18	7.26	1	0.007

Andaman Sea

Marine megafauna	**Parameter**	**B**	**95% CI**	**SE**	χ^2	**df**	***p*-value**
Rays	(Intercept)	2.85	(1.30 – 4.41)	0.79	12.94	1	< 0.001
	CG	4.43	(2.82 – 6.03)	0.82	29.26	1	< 0.001
	FDG	2.47	(0.27 – 4.67)	1.12	4.82	1	0.028
	FRR	3.55	(2.00 – 5.11)	0.79	20.05	1	< 0.001
	RG	4.08	(2.13 – 6.02)	0.99	16.90	1	< 0.001
	STN	3.65	(1.93 – 5.37)	0.88	17.35	1	< 0.001
Sea turtles	(Intercept)	-3.58	(-4.95 – -2.22)	0.70	26.42	1	< 0.001
	CG	1.56	(0.09 – 3.02)	0.75	4.34	1	0.037

2.4.4 Comparison of CPUEs among fishing gears

In the Gulf of Thailand, ray gillnets had the highest influence on ray CPUE (GLM, $\chi^2 = 7.96$, df = 1, $p = 0.005$). Pound nets had the highest influence on sea turtle CPUE (GLM, $\chi^2 = 23.31$, df = 1, $p < 0.001$). Ray gillnets had the highest influence on dolphin CPUE (GLM, $\chi^2 = 7.26$, df = 1, $p = 0.007$) (Table 2.6). In the Andaman Sea, crab gillnets had the highest influence on ray CPUE (GLM, $\chi^2 = 29.26$, df = 1, $p < 0.001$) and sea turtle CPUE (GLM, $\chi^2 = 4.34$, df = 1, $p = 0.037$) (Table 2.6). Comparisons among gears with significant differences ($p < 0.05$) in Estimated Marginal Means (EMM) reported CPUEs with corresponding *p*-values based on the Generalised Linear Model (GLM) are summarised in Table 2.7.

Table 2.7 Fishing gears with significant differences ($p < 0.05$) in estimated marginal means (EMM) of CPUEs (number of animals caught per vessel per year) of marine megafauna in small-scale fisheries in the Gulf of Thailand and the Andaman Sea during the period between September 2016 and December 2017 based on post hoc test in Generalized Linear Model (GLM). (CG = crab gillnets, CT = crab traps, FBG = fish bottom-set gillnets, FDG = fish drift gillnets, FRR = fishing rods and reels, HL = handlines, LL = longlines, MG = mackerel gillnets, PDN = pound nets, PN = push nets, QT = squid traps, RG = ray gillnets, STN = shrimp trammel nets and XG = other gillnets)

Gulf of Thailand

Marine megafauna	Gear 1	Gear 2	EMM difference of CPUE (Gear 1 – Gear 2)	SE	df	*p*-value
Rays	CG	FDG	507	141.5	1	0.019
	CG	PN	556	137.9	1	0.003
	STN	PN	184	50.4	1	0.015
Sea turtles	PDN	CG	7	2.1	1	0.017
	PDN	FBG	7	2.1	1	0.018
	PDN	FDG	8	2.0	1	0.007
	PDN	FRR	7	2.1	1	0.011
	PDN	LL	8	2.0	1	0.008
	PDN	PN	7	2.0	1	0.010
	PDN	STN	7	2.1	1	0.011
Cetaceans	CG	STN	1	0.04	1	< 0.001

Andaman Sea

Marine megafauna	Gear 1	Gear 2	EMM difference of CPUE (Gear 1 – Gear 2)	SE	df	*p*-value
Rays	CG	CT	1333	298.0	1	< 0.001
	CG	FBG	1437	290.9	1	< 0.001
	CG	FDG	1243	333.4	1	0.015
	CG	HL	1447	290.8	1	< 0.001
	CG	LL	1363	294.4	1	< 0.001
	CG	MG	1429	291.1	1	< 0.001
	CG	XG	1430	291.1	1	< 0.001
	FRR	CT	489	65.2	1	< 0.001
	FRR	FBG	593	5.3	1	< 0.001
	FRR	HL	603	0.7	1	< 0.001
	FRR	LL	519	45.8	1	< 0.001
	FRR	MG	585	13.8	1	< 0.001
	FRR	XG	587	13.7	1	< 0.001
Sharks	RG	QT	1	0.2	1	< 0.001

2.5 | Discussion

2.5.1 Dominant catching gears

This study presents the first estimates of catch per unite effort (CPUE) and annual catch of marine megafauna (rays, sharks, sea turtles, cetaceans and dugong) in Thai SSF. Crab gillnets and shrimp trammel nets were the gears responsible for the majority of catches for all marine megafauna groups in Thailand's SSF. Crab gillnets contributed a total of 79%, 73%, 80%, 95% and 72% of the annual estimated catches for rays, sharks, sea turtles, cetaceans and dugongs, respectively — whilst shrimp trammel nets contributed a total of 14%, 27%, 19%, 5% and 28%, respectively of the annual estimated catches. The high annual catch in crab gillnets was a product of high CPUE and relatively high effort whereas the high annual catch in shrimp trammel nets were mainly driven by a very high effort in the gear type compared to other gears. Crab gillnets and shrimp trammel nets were used by 46% and 40% of the interviewed fishers, respectively, and were used by 27% and 15% of all SSF fishers operating in Thai waters (DOF 2016), respectively.

Gillnets are globally recognised as a gear type responsible for high catches and mortalities of elasmobranchs (Dulvy et al. 2014; Ramírez-Amaro et al. 2013), sea turtles (Alfaro-Shigueto et al. 2018; Lewison et al. 2014; Wallace et al. 2013) and cetaceans (Brownell Jr. et al. 2019; Negri et al. 2012; Reeves et al. 2013). This study clearly demonstrates that gillnets are also a major threat to marine megafauna in Thailand. With a mean stretched mesh size of 10.0 cm (95% CI: 9.8 – 10.4), crab gillnets have the potential to catch large megafauna species (Reeves et al. 2013). Shrimp trammel nets have a smaller mean mesh size of 4.2 cm (95% CI: 4.1 – 4.3) and are therefore more likely to impact smaller megafauna species. The relatively low annual estimated catches of cetaceans and dugongs in the Andaman Sea suggest that the questionnaire did not fully cover catch of these megafauna groups. Further studies should therefore increase sampling effort e.g. by conducting more interviews with fishers in different communities using gillnets and trammel nets to improve the confidence in the data and the links between catch and specific fishing gears.

As the two dominant gears contributing a major part of the Thai SSF megafauna catch, crab gillnets and shrimp trammel nets should be considered priority gear in need of comprehensive assessment, mitigation and management in the context of marine megafauna catches. Light-Emitting Diode (LED) lights on gillnets are the only sensory deterrents so far to result in promising catch reduction across multiple megafauna groups, including marine mammals, sea turtles and elasmobranchs (Lucas & Berggren 2022) and should be considered as part of future mitigation strategies and regulations. Further, acoustic and electrosensory deterrents are also recommended in field trials for cetaceans and elasmobranchs, respectively (Lucas & Berggren 2022). Nevertheless, catch reduction efforts and mitigation success are substantially depended on willingness, collaboration and compliance of the fishers (Alava et al. 2019).

2.5.2 Concerns regarding ray and shark catches

This study further indicates that Thai SSF are likely to affect populations of endangered and vulnerable species of rays and sharks. Ray catches were dominated by small sting/whiprays (92%) which are commonly found in Thai waters (Krajangdara 2017). The remaining 8% consisted mainly of butterfly rays (*Gymnura* spp.) and eagle rays (*Aetobatus* spp. *and Aetomylaeus* spp.), two species groups that have a number of listed as threatened by the IUCN Red List of Threatened Species such as zonetail butterfly ray (*Gymnura zonura*), “Endangered” (Sherman et al. 2021) and mottled eagle ray (*Aetomylaeus maculatus*), “Endangered” (Rigby et al. 2020). Bamboo sharks and reef sharks (*Carcharhinus* spp.) including several species listed as “Endangered” (Simpfendorfer et al. 2020; VanderWright et al. 2020b) and

“Vulnerable” (Rigby et al. 2021; VanderWright et al. 2020a) contributed 82% and 16% to shark’s annual estimated catch, respectively. The remaining 2% was mostly contributed by nurse shark (*Nebrius ferrugineus*), “Vulnerable” (Simpfendorfer et al. 2021); zebra shark (*Stegostoma fasciatum*), “Endangered” (Dudgeon et al. 2019); and hammerhead sharks (*Sphyrna* spp.), “Critically Endangered” (Rigby et al. 2019). With high annual estimated catches of rays [5,662,024 (95% CI: 4,097,779 – 7,817,707)] and sharks [457,864 (95% CI: 192,352 – 969,166)], it is probable that the SSF in Thailand will have negative impacts on the sustainability of many ray and shark species.

It is worth mentioning that rays and sharks hold a market value as raw materials for restaurants and leather-wear industries (Krajangdara 2014), and also being consumed and sold by 87% of the interviewed fishers. Although rays and sharks are generally considered as non-target species in Thai SSF, and it has previously been stated that there are no specific gears to catch rays and sharks in Thailand (Krajangdara 2014), the results of this study indicate otherwise. Many interviewed fishers reported using ray gillnets and longlines to target rays (and possibly sharks). These were also the gear, in addition to crab gillnets, with the highest CPUEs for rays. However, longlines contributed relatively little to the annual estimated catch due to low efforts (DOF 2016).

2.5.3 Concerns regarding sea turtle catch

The results indicate the gillnets including pound nets, ray and crab gillnets are of particular concern and threat to sea turtles in Thailand. These results resonate with assessments in other regions e.g. Ecuador, Peru, and Chile (Alfaro-Shigueto et al. 2018; Wallace et al. 2013). Although crab gillnets appeared to dominate the sea turtle catch with respect to the annual estimated catch, pound nets and ray gillnets (which had relatively higher CPUEs than crab gillnets) may also have a significant catch, but these gears were excluded from the total catch extrapolation since effort for these gears were not available in the official statistics (DOF 2016). Beside gillnets, longlines have been reported as another major SSF gear responsible for sea turtle catch with large sea turtle mortalities in many regions e.g. the Southeastern Pacific (Alfaro-Shigueto et al. 2011; Alfaro-Shigueto et al. 2018), the North Pacific (Peckham et al. 2007) and the Southwestern Indian Ocean (Temple et al. 2019). In contrast, the results in this study showed that both CPUEs and annual estimated catch of sea turtles in longlines were low indicating that this gear is currently not a major threat to sea turtles in Thai waters. Longlines were used by 8% of the interviewed fishers and only 1% of all Thai SSF fishers (DOF 2016).

Given the current lack of information about the different respective sea turtle species found in Thailand, this study cannot conclude if the estimated sea turtle catch is sustainable. However, the annual estimated catch [2,400 (95% CI: 1,610 – 3,537)] is a serious cause for concern given that all species caught: green turtle (69%), hawksbill turtle (24%) and Olive Ridley turtle (*Lepidochelys olivacea*) (7%) are listed by the IUCN Red List as Endangered (Seminoff 2004), Critically Endangered (Mortimer & Donnelly 2008) and Vulnerable (Abreu-Grobois & Plotkin 2008), respectively. Moreover, it is possible that the fishers would underreport their catch to avoid potential legal prosecution even though the interviews were strictly confidential. Despite being experienced in how to utilise sea turtles (e.g. meat, shell and egg), all interviewed fishers were aware of the Wild Animal Reservation and Protection Act (GG 1992; GG 2014; GG 2019) and 92% reported that they released any live caught sea turtles while the remaining 8% reported to discard any sea turtles found dead in the nets.

2.5.4 Concerns regarding cetacean and dugong catches

The annual estimated catches presented in this study — 790 (95% CI: 519 – 1,167) cetaceans and 72 (95% CI: 19 – 194) dugongs — indicated that SSF represent potential serious threats to cetaceans and dugongs. As the dugong and a number of cetacean species in Thailand are coastal inhabitants (Adulyanukosol et al. 2014) coupled with intrinsic factors of slow growth and low fecundity rates, they are particularly vulnerable to fisheries catch (Brownell Jr. et al. 2019; Pusineri et al. 2013; Temple et al. 2021). There is expressed concern for the species that are already listed as threatened by the IUCN Red List of Threatened Species: Irrawaddy dolphin (*Orcaella brevirostris*), "Endangered" (Minton et al. 2017); Indo-Pacific humpback dolphin (*Sousa chinensis*), "Vulnerable" (Jefferson et al. 2017); Indo-Pacific finless porpoise, "Vulnerable" (Wang & Reeves 2017); dugong, "Vulnerable" (Marsh & Sobtzick 2015); and Indo-Pacific bottlenose dolphins, "Near Threatened" (Braulik et al. 2019). The results of the questionnaires further showed that cetaceans and dugongs caught in fishing gears were released alive by 77% and 100% of the interviewed fishers, respectively. Yet, the remaining 23% of the cetacean catches were discarded dead and potentially represent a high mortality. Furthermore, the annual estimated catches of cetaceans and dugongs reported in this study should be considered minimum estimates. Notwithstanding that most fishers were positively and cooperative during the interviews, signs of anxiety and defensiveness were expressed by many. Potential fear of prosecution, despite assurance of confidentiality, may have influenced some fishers to not report their catch since cetaceans and dugongs are legally protected from hunting, possessing, and importing and exporting without a permit in Thailand (Ezekiel 2018; GG 1992; GG 2014; GG 2019).

Despite 550+ dead cetacean stranding cases recorded in Thailand from 1993 to 2009 where gillnet entanglement was identified as the likely mortality cause (Adulyanukosol et al. 2012a), there is currently no monitoring, mitigation or management in place in Thailand to investigate and address the issue of cetacean catch and bycatch. There are 27 cetacean and one sirenian species identified from Thai coastal waters (Adulyanukosol et al. 2014), but published information regarding population size and abundance are limited to a few species within a few areas (Hines et al. 2015; Jaroensutasinee et al. 2010; Jutapruet et al. 2015). To date, the results presented in this chapter represent the only available assessment of marine megafauna catches in SSF in Thailand.

2.5.5 Recommendations and future works

Questionnaire interviews with local fishers has been demonstrated as a quick and capable method to assess and provide useful information of the catch in regions where catch information are lacking (Amir et al. 2002; Kiszka 2012; Moore et al. 2010; Mustika et al. 2021). Further, questionnaire interviews are logistically and financially feasible for gathering catch data in SSF (Alfaro-Shigueto et al. 2018; Moore et al. 2010; Mustika et al. 2021). This study has provided the first assessment of marine megafauna catch in Thai SSF including occurrence, estimated total catch and composition across five megafauna groups at regional and species group levels. The presented data and results may serve as a baseline for future research and also indicate where conservation and management actions are needed to prevent further impact on already threatened species. This is particularly important as the annual estimated catches reported in this study should be considered as minimum estimates. This is highlighted by the fact that the Thai official fisheries statistics (DOF 2016) (Appendix 3) used for annual catch estimates itself represents minimum SSF effort as it only included approximately 15,000 SSF vessels classified by gear types and missing the additional 40,000+ SSF vessels reported to the Food and Agriculture Organisation (FAO) as other fishing vessels (FAO 2020a; Lymer et al. 2008).

The questionnaire interviews reported that megafauna catches occurred in 21 SSF gear types used by fishers in 2016 – 2017, however, only six of the 21 gears reported had vessel numbers/efforts available in the official statistics (DOF 2016). Hence, we were unable to include catch estimates for 10 gears in the extrapolated annual total catch estimates. Gillnets have been identified as the gear type with the highest catch numbers of megafauna in many other regions (Alfaro-Shigueto et al. 2018; Kiszka et al. 2009; Reeves et al. 2013). In this study, fish bottom-set gillnets, fish drift gillnets and ray gillnets were examples of the SSF gears that had high CPUEs according to the questionnaire data, but lacked effort in the official statistics (DOF 2016), and would potentially significantly contribute to the annual estimated catches. Therefore in future research, it is recommended that systematic assessment and documentation (whether they are official or independent) should cover all the SSF gears used by the fishers. In future investigations, it is further recommended to include these additional gear types to allow more comprehensive assessment, however, this would also require that the official statistics are extended to cover all gears used by Thai SSF.

The next step following this study should be to start recording all marine megafauna catch at landings sites. Following this an onboard vessel sampling scheme should be initiated with independent observers or using remote electronic video monitoring (Bartholomew et al. 2018; WWF 2017). Furthermore, future research would also benefit if the official Thai fisheries efforts and catch per gear type were made available and/or published to allow comprehensive assessments. In conclusion, the results highlight the need for comprehensive assessment of marine megafauna catch in Thai SSF to facilitate evidence-based management of these vulnerable species.

CHAPTER 3

Spatio-Temporal Variations in Occurrence and Foraging Occurrence of Coastal Odontocetes off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Central-Western Gulf of Thailand, Based on Passive Acoustic Monitoring

3.1 | Abstract

Coastal odontocetes in the central-western Gulf of Thailand are threatened by continuous expansion of anthropogenic activities. Understanding the spatio-temporal patterns in distribution, occurrence and behaviour is vital to create effective conservation and management to prevent extirpation of resident endangered and vulnerable species. In this study, passive acoustic monitoring (PAM) was used to investigate the spatio-temporal variations in occurrence and foraging occurrence of three sympatric odontocete species: Irrawaddy dolphin (*Orcaella brevirostris*), Indo-Pacific humpback dolphin (*Sousa chinensis*) and Indo-Pacific finless porpoise (*Neophocaena phocaenoides*) off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand. Cetacean click recorders (C-PODs) were deployed at three locations: Laem Thuat Pier, Taled Bay and Thong Node Bay; for eight months during May – September 2019 and February – April 2020. To date the C-POD software does not include algorithms to acoustically differentiate the clicks between the three species and therefore this study investigated odontocetes rather than the individual species occurrence and foraging occurrence. Odontocete occurrence and foraging occurrence were investigated using echolocation click train detection positive minutes (DPM) and proportion of foraging click trains per hour (FPH), respectively. DPM and FPH were analysed with respect to spatial (site) and temporal (hour, month, tide phase and moon phase) factors using Generalised Additive Models (GAMs). Laem Thuat Pier had the highest levels of DPM and FPH possibly influenced by the nutrient-rich water entering the area from the Don Sak River providing high productivity and availability of dolphin prey. The GAM analyses showed that odontocete occurrence was significantly influenced by all temporal factors across all three sites, while the effect of temporal factors on foraging occurrence varied among sites. The results indicate the area off Laem Thuat Pier is an important area for odontocete occurrence and foraging occurrence. Given the multitude of anthropogenic threats facing odontocetes in the area, conservation and management actions are recommended to ensure the animals are protected in the area off Laem Thuat Pier.

3.2 | Introduction

Effective conservation and management of wild animals require good understanding and comprehensive information and data from a number of disciplines, including distribution, abundance, ecology, behaviour and anthropogenic threats (Breen et al. 2017; Jefferson et al. 2009; Piwetz et al. 2021). This is particularly true for odontocetes that have comparatively slow growth, late maturity and low fecundity, that inhabit coastal areas with increased risk of anthropogenic caused mortality and disturbance (Brownell Jr. et al. 2019; Christiansen & Lusseau 2014; Erbe et al. 2018; Schoeman et al. 2020; Temple et al. 2021).

Odontocete distribution, occurrence and behaviour can be driven by: (1) abiotic factors including diel cycle (Nuuttila et al. 2017a), water depth (Rayment et al. 2010), tide phase (Lin et al. 2013), moon phase (Wang et al. 2015), sea surface temperature (Canadas & Vazquez 2017) and season (Chen et al. 2010); (2) biotic factors including prey availability (Amir et al. 2005) and predation pressure (Heithaus & Dill 2002); and (3) anthropogenic factors including: fisheries pressure (Breen et al. 2017), tourism pressure (Kassamali-Fox et al. 2020) and vessel traffic (Papale et al. 2012). Appropriate data collection method is the first essential step toward better understanding of odontocete ecology, particularly for the areas where such knowledge is limited, and will eventually help guide any necessary conservation and management strategies to mitigate potential negative effects from anthropogenic activities.

Passive Acoustic Monitoring (PAM) allows for fine-scale study of species that rely on sound for communication, navigation and prey detection and capture like odontocetes (Nuuttila et al. 2017a; Temple et al. 2016; Wang et al. 2015) and mysticetes (Risch et al. 2014; Romagosa et al. 2020; Schall et al. 2020) by detecting, recording and monitoring their acoustic activities, particularly odontocetes' use of echolocation click trains. PAM has been used to investigate cetacean occurrence (Fang et al. 2021; Munger et al. 2016; Temple et al. 2016), foraging activities (Nuuttila et al. 2017a; Temple et al. 2016), distribution (Elliott et al. 2011; Warren et al. 2021) and habitat use (Dähne et al. 2013; La Manna et al. 2014) at large temporal scales (Chelonia.co.uk 2019; Jaramillo-Legorreta et al. 2017) with consistent and comparable data. PAM creates minimal disturbance to cetaceans and their natural behaviours (Roberts & Read 2014). Further, PAM's performance and effectiveness are not significantly affected or limited by daylight, visibility, weather, sea state, surface glare, animal surface presence and observer bias, which hamper traditional visual surveys (Barlow et al. 2001; Nowacek et al. 2016). Moreover, PAM is likely more feasible and less financially limited compared to relatively expensive visual surveys by vessels or aircrafts at similar temporal scales (Dawson et al. 2008).

The central-western Gulf of Thailand comprises of the two coastal zones off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, where three sympatric odontocete species occur: Irrawaddy dolphin (*Orcaella brevirostris*), Indo-Pacific humpback dolphin (*Sousa chinensis*) and Indo-Pacific finless porpoise (*Neophocaena phocaenoides*) (Jutapruet et al. 2017).

Irrawaddy dolphin is listed as Endangered while Indo-Pacific humpback dolphin and Indo-Pacific finless porpoise are listed as Vulnerable by the IUCN Red List of Threatened Species (Jefferson et al. 2017; Minton et al. 2017; Wang & Reeves 2017). The abundance of Indo-Pacific humpback dolphin in the area off Don Sak was estimated to 193 (95% CI: 167 – 249) in 2013 (Jutapruet et al. 2015) and off Khanom to 49 individuals (no reported 95% confidence intervals) in 2009 (Jaroensutasinee et al. 2010). A new abundance estimate is provided in Chapter 5 of this thesis. There are currently no published abundance estimates for Irrawaddy dolphins or Indo-Pacific finless porpoises available for the central-western Gulf of Thailand. Vocalisation patterns for Indo-Pacific humpback dolphins have previously been described for the central-western Gulf of Thailand (Niu et al. 2021) and for Irrawaddy dolphins in Trat Bay, the eastern Gulf of Thailand (Niu et al. 2019).

Odontocetes in the central-western Gulf of Thailand are threatened by a number of anthropogenic activities including fisheries catch, dolphin-watching tourism, shipping, ferry traffic and continuous expansion of coastal development projects (Jutapruet et al. 2015). Currently there is limited understanding of the environmental drivers and potential effects of anthropogenic factors on the variation in occurrence and behaviour (e.g. foraging) of odontocetes in the central-western Gulf of Thailand (Jutapruet et al. 2015; Niu et al. 2021).

This study aims to provide the first independent investigation using PAM to assess the occurrence and foraging occurrence with respect to spatial and temporal factors of the three sympatric coastal odontocete species: Irrawaddy dolphin, Indo-Pacific humpback dolphin and Indo-Pacific finless porpoise occurring off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, in the central-western Gulf of Thailand. This study further aims to test PAM as a potential monitoring system for future research, management and conservation of coastal odontocetes in the central-western Gulf of Thailand.

3.3 | Methods

3.3.1 Study area

The study was conducted off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand (Figure 3.1) where the water depth ranges between 1 – 10 m with a bottom sediment of mud flats, sand and seagrass. Three seasons occur in the study area: summer (mid-February to mid-May), rainy (mid-May to mid-October), and winter (mid-October to mid-February).

3.3.2 Data collection

Passive Acoustic Monitoring (PAM) was conducted during eight months from May to September 2019 and February to April 2020 to investigate the occurrence and foraging occurrence of coastal odontocetes off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand (Figure 3.1). Cetacean echolocation click recorders (C-PODs) (Chelonia.co.uk 2019) were deployed at five sites: Laem Thuat Pier, Taled Bay, Thong Node Bay, Nok Taphao Island and Chueak Island, to collect the data for the study (Figure 3.1). However, the recorders at two sites: Nok Taphao Island and Chueak Island, were lost and no data were available for these sites.

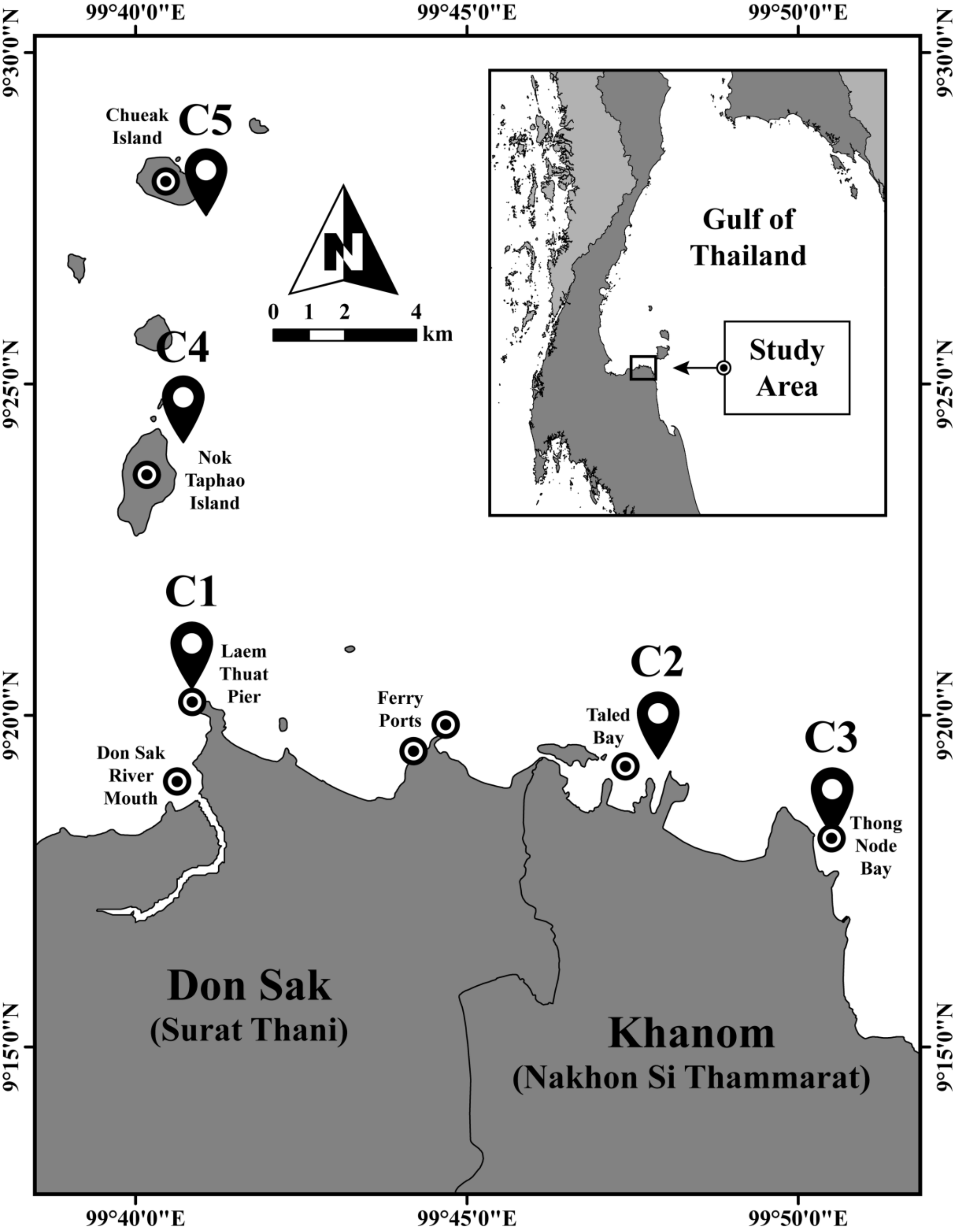


Figure 3.1 The deployment sites (C1 – C5) where passive acoustic monitoring was conducted using odontocete click recorders (C-POD, www.chelonia.co.uk) to investigate the spatio-temporal variation in the occurrence and foraging occurrence of coastal odontocetes off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand during May – September 2019 and February – April 2020. The two C-PODs deployed at C4 and C5 were lost and no data were available for these sites.

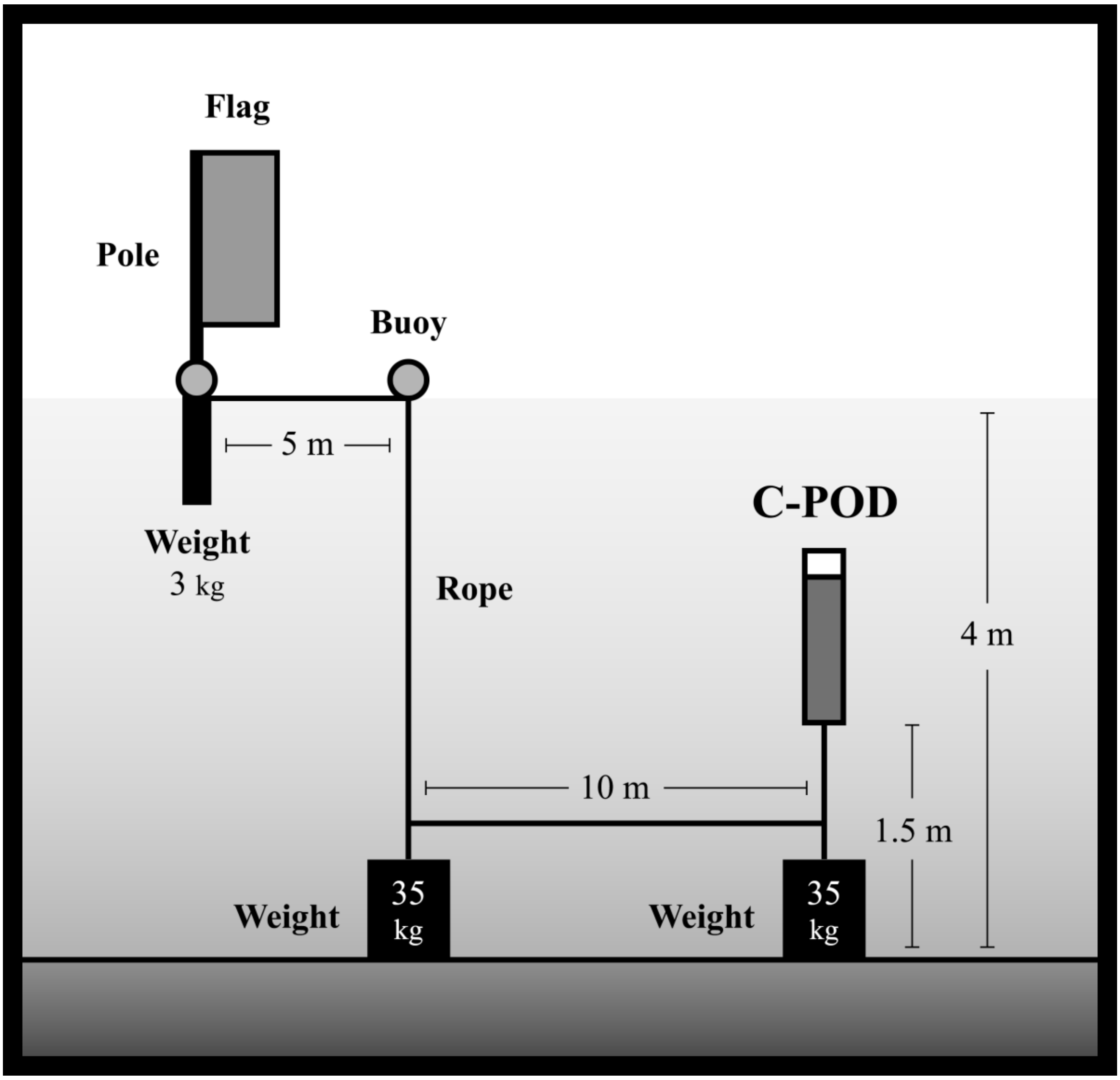


Figure 3.2 C-POD deployment set-up for passive acoustic monitoring at three deployment sites in Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand during May – September 2019 and February – April 2020

Before deployment of the C-PODs, in-person meetings were held with district head officers and community (village) headmen in Don Sak and Khanom to introduce the study and to discuss best deployment locations to minimise interaction and potential entanglement in fishing gears. We were strongly suggested not to deploy the C-PODs beyond 400 m from shore where small-scale and commercial fisheries use driftnets, bottomset nets, gillnets and trammel nets and in the areas where deployments might obstruct ferry traffic. As a result, C-POD deployment sites were decided based on prior information of odontocete occurrence (Jutapruet et al. 2017) and different levels of anthropogenic activities. Further, within each of their governing areas, community headmen informed the people and alerted the fishers through local social networks to be aware of the C-POD deployments. In addition, we posted lost-and-found messages with contact information about the C-PODs and surface buoys/flags (Figure 3.2).

C-PODs were deployed at five locations (Figure 3.1): “C1” at Laem Thuat Pier (9° 20' 27.54" N and 9°9 40' 50.1" E); “C2” at Taled Bay (9° 19' 23.34" N and 99° 47' 53.7" E); “C3” at Thong Node Bay (9° 18' 15.06" N and 99° 50' 30.84" E); “C4” at Nok Ta Phao Island (9° 24' 10.52" N and 99° 40' 42.78" E); and “C5” at Chueak Island (9° 27' 33.93" N and 99° 41' 3.84" E). C-PODs were deployed and anchored 1.5 m above the sea floor in 4 m depth (Figure 3.2). The bottom substrate at the C-POD deployment locations were mud with 3.5 – 5.5 m water depth depending on tidal changes, measured by a portable depth sounder (Hondex PS-7). C-PODs were retrieved and re-deployed every three weeks to download the data from the memory cards (swapping the memory cards). The C-PODs deployed at C4 and C5 were never retrieved after initial deployment and were considered lost. Furthermore, C-PODs were accidentally removed at least once from each site (C1 – C3) by fishers but these were returned following the lost-and-found message on the C-PODs. Due to the loss of the devices at locations C4 and C5, these locations were excluded from the study.

3.3.3 Data analysis

3.3.3.1 Click trains identification

Acoustic data collected from the C-PODs were processed and analysed using the C-POD software, CPOD.exe (Version 2.044) (Chelonia Limited, Cornwall, UK: www.chelonia.co.uk).

The GENENC classifier was used to identify the odontocete echolocation click trains. To date the C-POD software does not include algorithms to acoustically differentiate the clicks between Irrawaddy dolphins, Indo-Pacific humpback dolphins and Indo-Pacific finless porpoises. As a result, all identified click trains were considered as one amalgamated group of odontocete click trains. Only click trains with high and moderate qualities classified by the software were used in further analyses. It is possible for C-PODs to include environmental noise which can lead to false positives, particularly when used in shallow water environments when recordings may include significant reflections from surface water or bottom sediment (Chelonia.co.uk 2019). Therefore, click trains with < 6 clicks were discarded from the analyses to reduce the number of false positives that may be generated by non-odontocete sound producing sources (Lin et al. 2013; Wang et al. 2019b).

3.3.3.2 Occurrence and foraging occurrence

Echolocation click trains were used as a measure of occurrence and foraging occurrence of odontocetes in the study area. Detection Positive Minutes (DPM, a minute in which at least one odontocete click train is detected) were used as data for dolphin occurrence and DPM per hour were exported from the C-POD software and used in the analyses. Buzz Positive Minutes (BPM), click trains with Inter-Click Intervals (ICIs) of < 10 ms, were used as data to indicate odontocete foraging occurrence (Nuuttila et al. 2013) and analysed as BPM per hour. DPM/BPM per hour ranged from 0 – 60. Further, as foraging click trains are generally preceded by, and not independent of, regular click trains, variation in foraging occurrence was investigated as a proportion of all recorded click trains. DPM and BPM positive minutes were extracted from the data for each hour in RStudio (Version 1.3.959) using “lubridate” (Grolemund & Wickham 2011) and “tidyverse” packages (R Core Team 2020). BPM data were then arranged and aggregated into designated dates and times matching the DPM dataset using “data.table” package (Dowle & Srinivasan 2021). Finally, to address the fact that foraging clicks are not independent of regular clicks (the latter precedes the foraging clicks in a buzz click train), combined dataset comprised of DPM and BPM per hour with the same timestamp was created allowing the calculation of Foraging Proportion per Hour, FPH (BPM/DPM per hour) and used to investigate variation in foraging occurrence.

There is a possibility that the identified BPM may have included social buzzes, which are rapidly pulsed signals with short ICIs of < 10 ms (similar to foraging buzzes) but used during socialising behaviours (Martin et al. 2019). However, odontocete surface and underwater behaviours were not observed in this study, and thus the correlation between buzzes and social behaviours could not be made. This study therefore assumed all identified BPMs with ICIs of < 10 ms were foraging buzzes and included in the analyses.

3.3.3.3 Temporal and abiotic environmental factors

This study investigated four temporal and abiotic environmental factors (hour, month, tide phase and moon phase) as drivers for odontocete occurrence and foraging occurrence. Hour was defined as the hour of the day/night ranging from 0 – 23. Month ranged from February to September. Tide phase comprised of four phases: flood tide, high tide, ebb tide and low tide. Moon phase comprised of four phases: first quarter, full moon, last quarter and new moon.

To fit tide phase and moon phase categorical data into GAMs, these were converted into numeric data by artificially varying their values ranging from 0 to 100 according to the duration of each phase in each cycle. For tide phase: > 0 to 25 were flood tide; > 25 to 50 were high tide; > 50 to 75 were ebb tide; and > 75 to 100 were low tide. For moon phase: > 0 to 25 were first quarter; > 25 to 50 were full moon; > 50 to 75 were last quarter; and > 75 to 100 were new moon.

3.3.3.4 Generalised Additive Models

Generalised Additive Models (GAMs) were used to investigate the temporal and abiotic environmental factors as drivers for occurrence and foraging occurrence of odontocetes. GAMs were also used to investigate potential variation in odontocete occurrence and foraging among the three C-POD deployment sites. GAM analyses were performed in R Studio (Version 1.3.959) (R Core Team 2020) using “mgcv” package (Wood 2017). Independency of the temporal and environmental factors (hour, month, tide phase and moon phase) were tested using the concurvity function (generalisation of co-linearity) in “mgcv” package (Table 3.1). To investigate the spatial variation (site) of the occurrence (DPM) and foraging occurrence (FPH) among the three C-POD deployment sites, GAMs were calculated following the formula:

$$g(\text{DPM}) = f(\text{Hour}) + f(\text{Month}) + f(\text{Tide phase}) + f(\text{Moon phase}) + f(\text{Site})$$

$$g(\text{FPH}) = f(\text{Hour}) + f(\text{Month}) + f(\text{Tide phase}) + f(\text{Moon phase}) + f(\text{Site})$$

To investigate the temporal variation (hour, month, tide phase and moon phase) of the occurrence (DPM) and foraging occurrence (FPH) for each C-POD deployment site, GAMs were calculated following the formula:

$$g(\text{DPM}) = f(\text{Hour}) + f(\text{Month}) + f(\text{Tide phase}) + f(\text{Moon phase})$$

$$g(\text{FPH}) = f(\text{Hour}) + f(\text{Month}) + f(\text{Tide phase}) + f(\text{Moon phase})$$

In the GAMs, to account for overdispersion in the data, family "nb" (negative binomial) and "binomial" were used for DPM and FPH models, respectively. Method "REML" (restricted maximum likelihood) was used as a variance estimator. Smooth classes (bs) were selected to fit the data nature for each abiotic environmental factor. Splines (k) were manually adjusted following the suggestions from "gam.check" (a function in the mgcv package) for more accurate interpretations of the response variables.

Table 3.1 Output of concurvity (generalisation of co-linearity) in Generalised Additive Models (GAMs) (Wood 2017) between four temporal abiotic environmental factors (hour, month, tide phase and moon phase) for Detection Positive Minutes (DPM) and Foraging Proportion per Hour (FPH) observed from odontocetes off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand during May – July 2019. The value ≤ 0.5 indicates that the two parameters are independent to one another.

Detection Positive Minutes (DPM)				
Parameter	**s(Hour)**	**s(Month)**	**s(TidePhase)**	**s(MoonPhase)**
s(Hour)	1	0.0003	0.2444	0.0001
s(Month)	0.0003	1	0.0002	0.1758
s(TidePhase)	0.2444	0.0002	1	0.0003
s(MoonPhase)	0.0001	0.1758	0.0003	1
Foraging Proportion per Hour (FPH)				
Parameter	**s(Hour)**	**s(Month)**	**s(TidePhase)**	**s(MoonPhase)**
s(Hour)	1	0.0003	0.2444	0.0001
s(Month)	0.0003	1	0.0002	0.1758
s(TidePhase)	0.2444	0.0002	1	0.0003
s(MoonPhase)	0.0001	0.1758	0.0003	1

Post hoc tests (pairwise comparisons) (Shiraishi et al. 2019) were made to investigate if there were significant differences in the occurrence and foraging occurrence between the three C-POD deployment sites using estimated marginal means (EMM) as a measure. Post hoc tests were performed in R Studio (Version 1.3.959) (R Core Team 2020) using "emmeans" package (Lenth 2021). Bonferroni correction (Bonferroni 1936) was applied in the post hoc tests to adjust significance levels for multiple tests to avoid Type I error.

3.3.4 Ethical approval

This study received ethical approval from the Newcastle University Ethics Committee (reference number: 12246/2018) and the Animal Welfare and Ethical Review Body (AWERB), Faculty of Medical Sciences, Newcastle University (Project ID number: ID 765).

3.4 | Results

3.4.1 Occurrence and foraging occurrence

PAM collectively recorded 11,184 hours (466 days) of data across the three C-POD deployment sites (Table 3.2). In total, C-PODs recorded 1,845 hours and 625 hours of Detection Positive Minutes (DPM) and Buzz Positive Minutes (BPM), respectively (Table 3.2). Mean DPM, BPM and Foraging Proportion per Hour (FPH) with corresponding 95% confidence intervals across the three C-POD deployment sites are presented in Table 3.2.

GAMs explained 22.5% and 34.6% of the deviances for dolphin occurrence and foraging occurrence, respectively (Table 3.3). The GAM analyses showed that the odontocete occurrence among the three C-POD deployment sites were significantly driven by site (GAMs, $p < 0.0001$), hour (GAMs, $\chi^2 = 241.75$, $p < 0.0001$), month (GAMs, $\chi^2 = 263.34$, $p < 0.0001$), tide phase (GAMs, $\chi^2 = 54.55$, $p < 0.0001$) and moon phase (GAMs, $\chi^2 = 32.09$, $p < 0.0001$)

(Table 3.3). Foraging occurrence of odontocetes among the three C-POD deployment sites were also significantly driven by site (GAMs, $p < 0.0001$), hour (GAMs, $\chi^2 = 109.91$, $p < 0.0001$), month (GAMs, $\chi^2 = 510.95$, $p < 0.0001$), tide phase (GAMs, $\chi^2 = 12.5$, $p = 0.0008$) and moon phase (GAMs, $\chi^2 = 15.62$, $p = 0.0014$) (Table 3.3).

Table 3.2 Summary of collected and processed C-POD data at three deployment sites off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand during May – September 2019 and February – April 2020. (DPM = Detection Positive Minutes, BPM = Buzz Positive Minutes, FPH = Foraging Proportion per Hour)

Site	Deployment duration (hrs)	Sum DPM (hrs)	Sum BPM (hrs)
C1	3931	1383	540
C2	3611	309	52
C3	3642	154	34
Total	**11184**	**1845**	**625**
Site	**Mean DPM (95% CI)**	**Mean BPM (95% CI)**	**Mean FPH (95% CI)**
C1	21.1 (20.5 – 21.7)	8.2 (7.9 – 8.6)	0.276 (0.265 – 0.286)
C2	5.1 (4.8 – 5.4)	0.9 (0.8 – 1.0)	0.050 (0.045 – 0.054)
C3	2.5 (2.3 – 2.7)	0.6 (0.5 – 0.6)	0.048 (0.043 – 0.053)

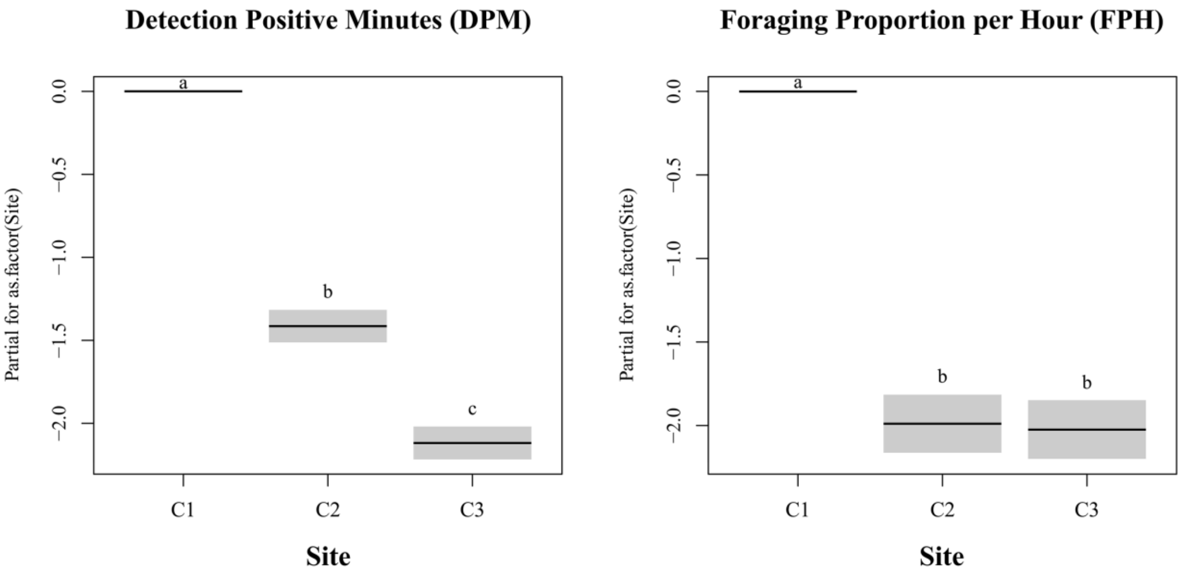


Figure 3.3 Generalised Additive Models (GAMs) outputs for the occurrence levels of Detection Positive Minutes (DPM) and Foraging Proportion per Hour (FPH) observed from coastal odontocetes at three C-POD deployment sites off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand during May – September 2019 and February – April 2020. The grey areas represent the 95% confidence intervals. Different letters above the GAM plots indicate the site pairs with significant differences in DPM or FPH ($p < 0.05$).

The EMM analyses showed that Laem Thuat Pier (site C1) had the highest levels of DPM and FPH among the three C-POD deployment sites (Figure 3.3). Laem Thuat Pier had significantly higher DPM compared to site Taled Bay (site C2) (EMM, *t*-ratio = 30.233, df = 11,181, $p < 0.0001$) and Thong Node Bay (site C3) (EMM, *t*-ratio = 46.298, df = 11,181, $p < 0.0001$) (Figure 3.3 and Table 3.4). Laem Thuat Pier also had significantly higher FPH compared to Taled Bay (EMM, *t*-ratio = 23.511, df = 11,181, $p < 0.0001$) and Thong Node Bay (EMM, *t*-ratio = 23.698, df = 11,181, $p < 0.0001$) (Figure 3.3 and Table 3.4). Taled Bay had significantly higher DPM compared to Thong Node Bay (EMM, *t*-ratio = 15.939, df = 11,181, $p < 0.0001$), however, there was no significant difference in FPH between the two sites indicating that there was higher occurrence of odontocetes in Taled Bay but no difference in foraging occurrence between the two sites (Figure 3.3 and Table 3.4).

Table 3.3 Generalised Additive Models (GAMs) outputs of observed spatial factor (site) and temporal environmental factors (hour, month, tide phase and moon phase) among the three C-POD deployment sites and their significance on Detection Positive Minutes (DPM) and Foraging Proportion per Hour (FPH) produced by coastal odontocetes off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand during May – September 2019 and February – April 2020. (SE = standard error, edf = estimated degrees of freedom, Ref.df = reference degrees of freedom)

Detection Positive Minutes (DPM)					
Spatial factor	**Estimate**	**SE**	**z-value**	**Pr(>|z|)**	**Significance**
C1	2.93	0.03	94.48	< 0.0001	Yes
C2	-1.39	0.05	-30.21	< 0.0001	Yes
C3	-2.16	0.05	-46.39	< 0.0001	Yes
Temporal factor	**edf**	**Ref.df**	**$\chi2$**	***p*-value**	**Significance**
Hour	5.656	22	241.75	< 0.0001	Yes
Month	6.671	6.95	263.34	< 0.0001	Yes
Tide phase	4.948	8	54.55	< 0.0001	Yes
Moon phase	4.387	8	32.09	< 0.0001	Yes
(R-sq. (adj) = 0.435, Deviance explained = 22.5%, -REML = 29550, Scale est. = 1, n = 11184)					

Foraging Proportion per Hour (FPH)					
Spatial factor	**Estimate**	**SE**	**z-value**	**Pr(>|z|)**	**Significance**
C1	-1.07	0.04	-26.05	< 0.0001	Yes
C2	-2.17	0.09	-24.17	< 0.0001	Yes
C3	-2.26	0.09	-25.06	< 0.0001	Yes
Temporal factor	**edf**	**Ref.df**	**$\chi2$**	***p*-value**	**Significance**
Hour	4.173	22	109.91	< 0.0001	Yes
Month	6.926	6.99	510.95	< 0.0001	Yes
Tide phase	2.291	8	12.5	0.0008	Yes
Moon phase	3.956	8	15.62	0.0014	Yes
(R-sq. (adj) = 0.419, Deviance explained = 34.6%, -REML = 2711, Scale est. = 1, n = 11184)					

Table 3.4 Post hoc tests outputs from Estimated Marginal Means (EMM) analyses for the differences in the EMM of Detection Positive Minutes (DPM) and Foraging Proportion per Hour (FPH) among the three C-POD deployment sites (Contrast) produced by coastal odontocetes off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand during May – September 2019 and February – April 2020. (SE = standard error, df = degrees of freedom)

Detection Positive Minutes (DPM)						
Contrast	**EMM difference**	**SE**	**df**	***t*-ratio**	***p*-value**	**Significance**
C1 - C2	1.415	0.047	7541	30.233	< 0.0001	Yes
C1 - C3	2.118	0.047	7572	46.298	< 0.0001	Yes
C2 - C3	0.704	0.049	7252	15.939	< 0.0001	Yes
Foraging Proportion per Hour (FPH)						
Contrast	**EMM difference**	**SE**	**df**	***t*-ratio**	***p*-value**	**Significance**
C1 - C2	1.989	0.085	7541	23.511	< 0.0001	Yes
C1 - C3	2.024	0.085	7572	23.698	< 0.0001	Yes
C2 - C3	0.035	0.109	7252	0.316	1	No

3.4.2 Influences of temporal and abiotic environmental factors on the occurrence and foraging occurrence

The GAM analyses showed that all four factors (hour, month, tide phase and moon phase) significantly affected DPM at all three sites (Table 3.5). All four factors were also significant drivers for FPH at Laem Thuat Pier (site C1), but only two factors (month and tide phase) were significant for FPH at Taled Bay (site C2), while the two factors (hour and month) were significant for FPH at Thong Node Bay (site C3) (Table 3.5). Across the three sites, DPM and FPH were generally higher during the night (21:00 – 3:00 hrs), although this was less pronounced at Taled Bay; in June – July (and in March at Laem Thuat Pier and Taled Bay); during high and ebb tides (except DPM at Laem Thuat Pier and FPH at Laem Thuat Pier and Thong Node Bay); and during new moon and first quarter of moon phase (except FPH at Taled Bay) (Figure 3.4 – 3.9).

Table 3.5 Generalised Additive Models (GAMs) outputs of observed temporal and abiotic environmental factors at the three C-POD deployment sites and their significance on Detection Positive Minutes (DPM) and Foraging Proportion per Hour (FPH) produced by coastal odontocetes off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand during May – September 2019 and February – April 2020. (edf = estimated degrees of freedom, Ref.df = reference degrees of freedom)

Detection Positive Minutes (DPM)

Site	**Factor**	**edf**	**Ref.df**	**χ^2**	***p*-value**	**Significance**
C1	Hour	8.60	22	278.33	< 0.0001	Yes
	Month	6.97	6.99	898.39	< 0.0001	Yes
	Tide phase	4.08	8	26.82	< 0.0001	Yes
	Moon phase	4.77	8	27.35	< 0.0001	Yes
	(R-sq. (adj) = 0.348, Deviance explained = 19.8%, -REML = 15337, Scale est. = 1, n = 3931)					
C2	Hour	2.90	22	17.71	0.0001	Yes
	Month	6.60	6.92	127.61	< 0.0001	Yes
	Tide phase	3.77	8	38.76	< 0.0001	Yes
	Moon phase	5.06	8	15.71	0.0041	Yes
	(R-sq. (adj) = 0.0767, Deviance explained = 6.91%, -REML = 7637.8, Scale est. = 1, n = 3611)					
C3	Hour	6.66	22	92.57	< 0.0001	Yes
	Month	4.81	5.53	43.16	< 0.0001	Yes
	Tide phase	4.13	8	34.77	< 0.0001	Yes
	Moon phase	3.26	8	30.00	< 0.0001	Yes
	(R-sq. (adj) = 0.122, Deviance explained = 11.1%, -REML = 5209, Scale est. = 1, n = 3642)					

Foraging Proportion per Hour (FPH)

Site	**Factor**	**edf**	**Ref.df**	**χ^2**	***p*-value**	**Significance**
C1	Hour	4.84	22	108.65	< 0.0001	Yes
	Month	6.94	6.99	686.35	< 0.0001	Yes
	Tide phase	2.28	8	13.10	0.0006	Yes
	Moon phase	5.12	8	54.37	< 0.0001	Yes
	(R-sq. (adj) = 0.484, Deviance explained = 41%, -REML = 1388.2, Scale est. = 1, n = 3931)					
C2	Hour	0.88	22	1.40	0.1779	No
	Month	4.92	5.76	15.29	0.0164	Yes
	Tide phase	2.37	8	9.71	0.0037	Yes
	Moon phase	0.29	8	0.32	0.3221	No
	(R-sq. (adj) = 0.0243, Deviance explained = 5.32%, -REML = 568.99, Scale est. = 1, n = 3611)					
C3	Hour	3.46	22	38.34	< 0.0001	Yes
	Month	1.00	1.01	20.05	< 0.0001	Yes
	Tide phase	0.01	8	0.01	0.4233	No
	Moon phase	1.37	8	3.16	0.0804	No
	(R-sq. (adj) = 0.0518, Deviance explained = 8.27%, -REML = 565.27, Scale est. = 1, n = 3642)					

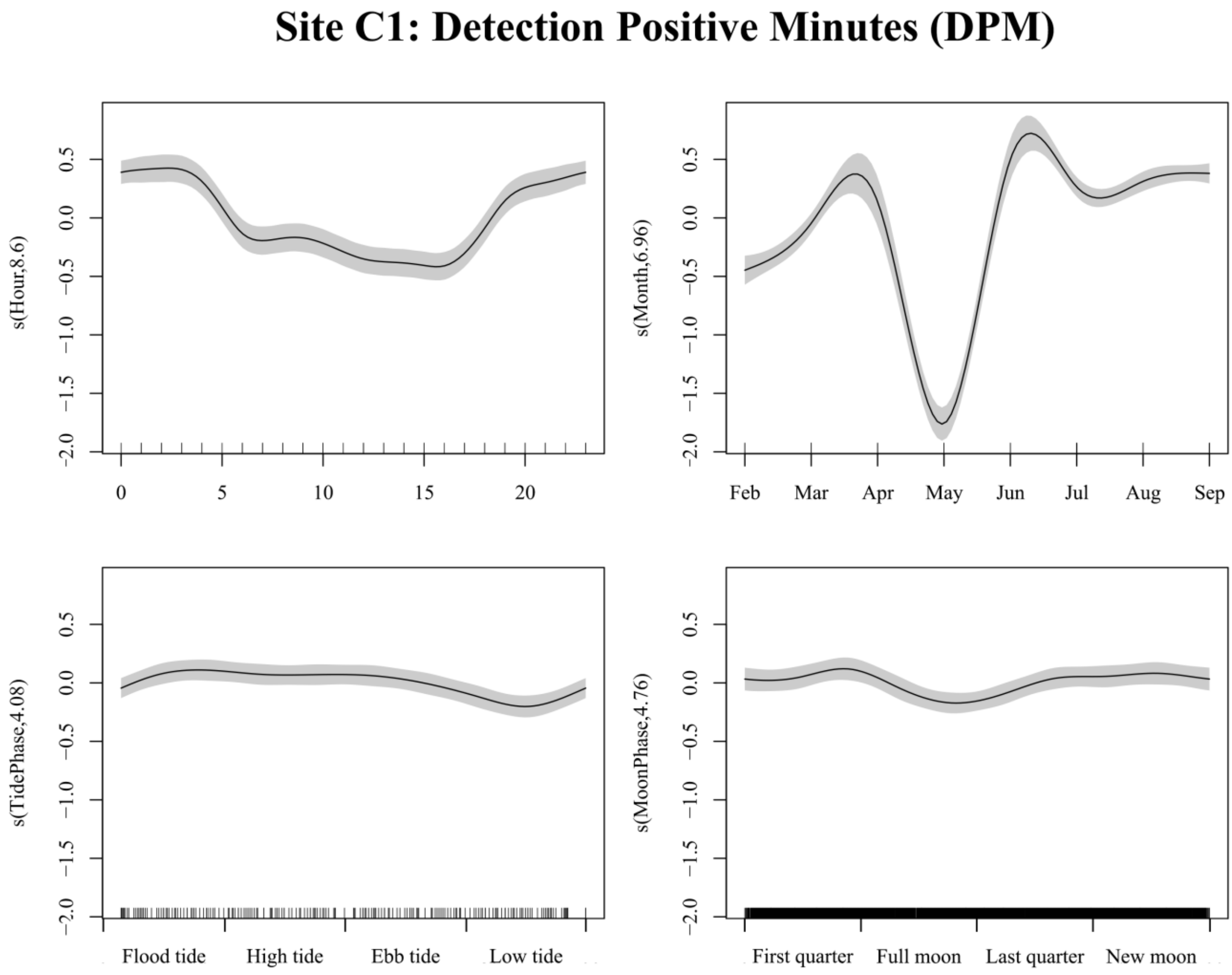


Figure 3.4 Generalised Additive Models (GAMs) outputs for the relationships between Detection Positive Minutes (DPM) and temporal and abiotic environmental factors observed from coastal odontocetes at C-POD deployment site C1 off Don Sak, Surat Thani, Thailand during May – September 2019 and February – April 2020. The rug plots along the x-axis indicate the density of observations for each factor. The grey areas around the smoothed-plotted curves represent the 95% confidence intervals.

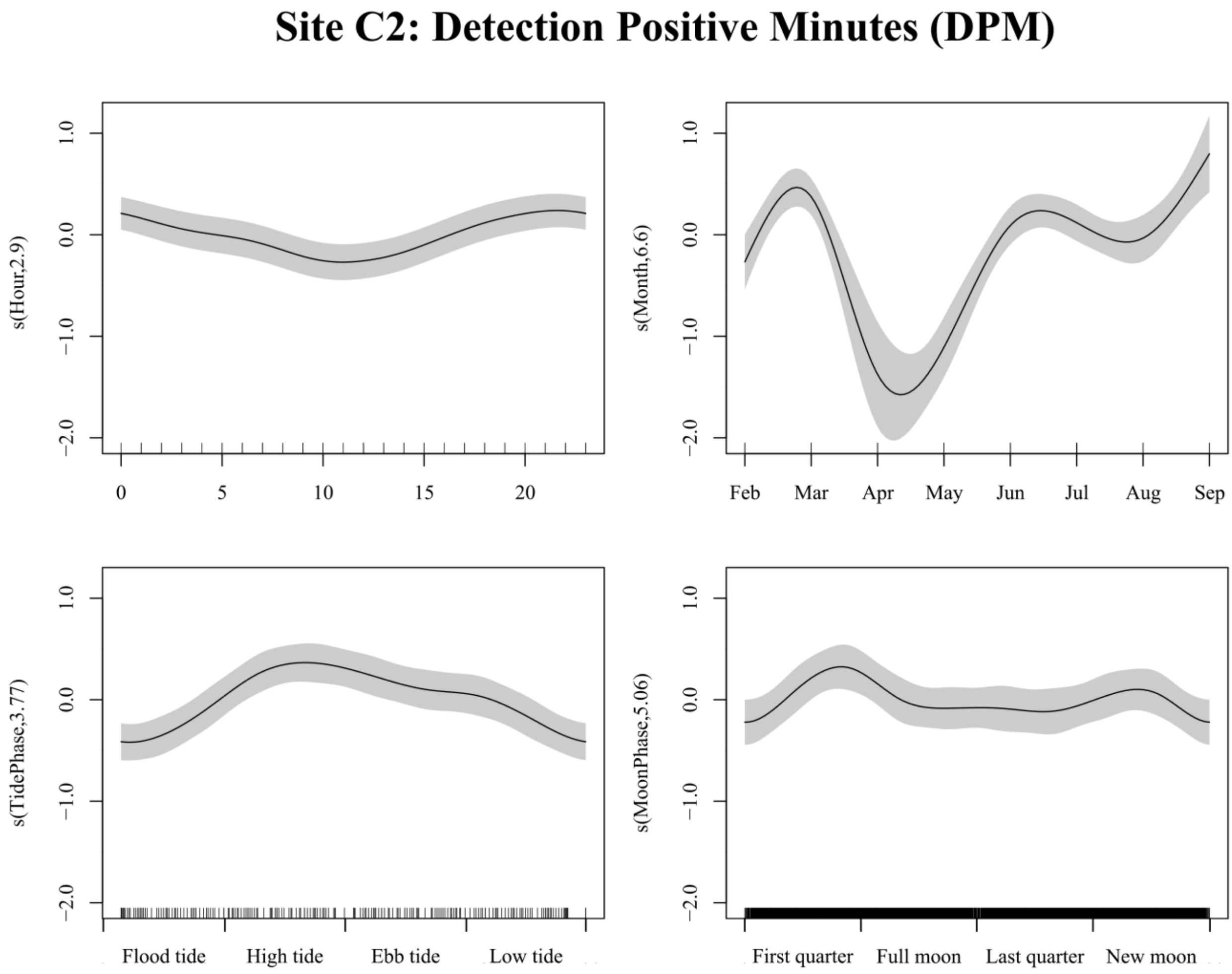


Figure 3.5 Generalised Additive Models (GAMs) outputs for the relationships between Detection Positive Minutes (DPM) and temporal and abiotic environmental factors observed from coastal odontocetes at C-POD deployment site C2 off Khanom, Nakhon Si Thammarat, Thailand during May – September 2019 and February – April 2020. The rug plots along the x-axis indicate the density of observations for each factor. The grey areas around the smoothed-plotted curves represent the 95% confidence intervals.

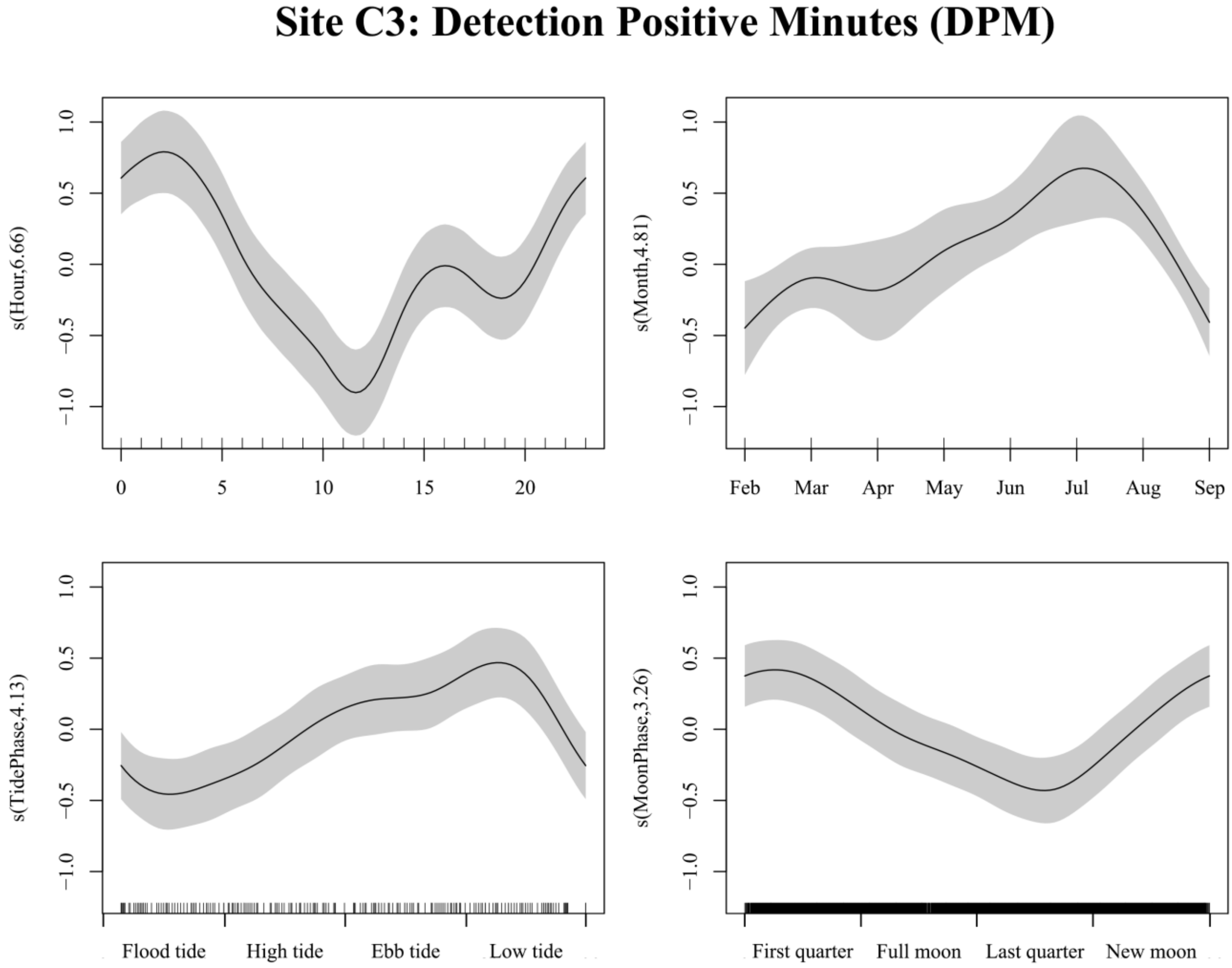


Figure 3.6 Generalised Additive Models (GAMs) outputs for the relationships between Detection Positive Minutes (DPM) and temporal and abiotic environmental factors observed from coastal odontocetes at C-POD deployment site C3 off Khanom, Nakhon Si Thammarat, Thailand during May – September 2019 and February – April 2020. The rug plots along the x-axis indicate the density of observations for each factor. The grey areas around the smoothed-plotted curves represent the 95% confidence intervals.

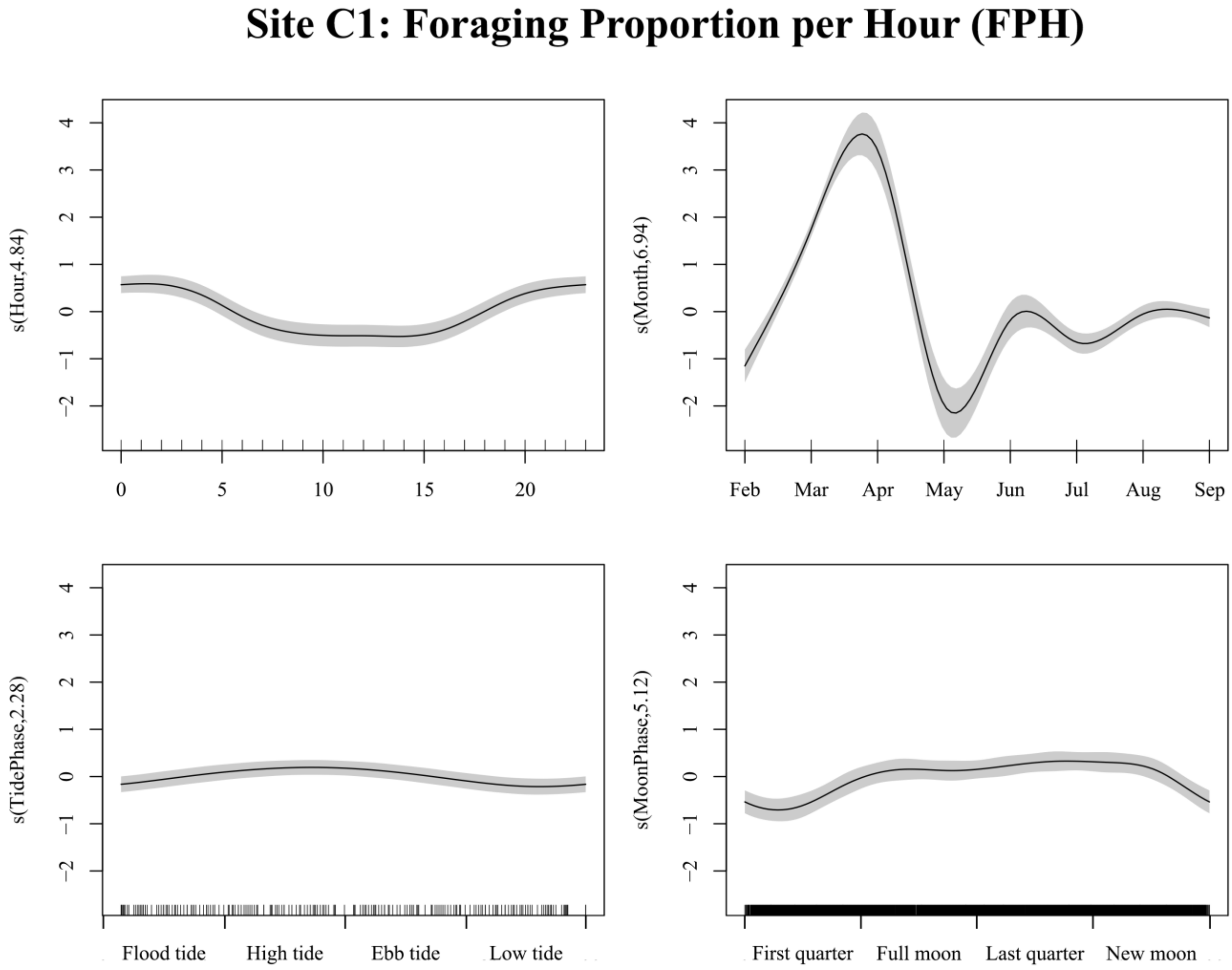

Site C1: Foraging Proportion per Hour (FPH)

Figure 3.7 Generalised Additive Models (GAMs) outputs for the relationships between Foraging Proportion per Hour (FPH) and temporal and abiotic environmental factors observed from coastal odontocetes at C-POD deployment site C1 off Don Sak, Surat Thani, Thailand during May – September 2019 and February – April 2020. The rug plots along the x-axis indicate the density of observations for each factor. The grey areas around the smoothed-plotted curves represent the 95% confidence intervals.

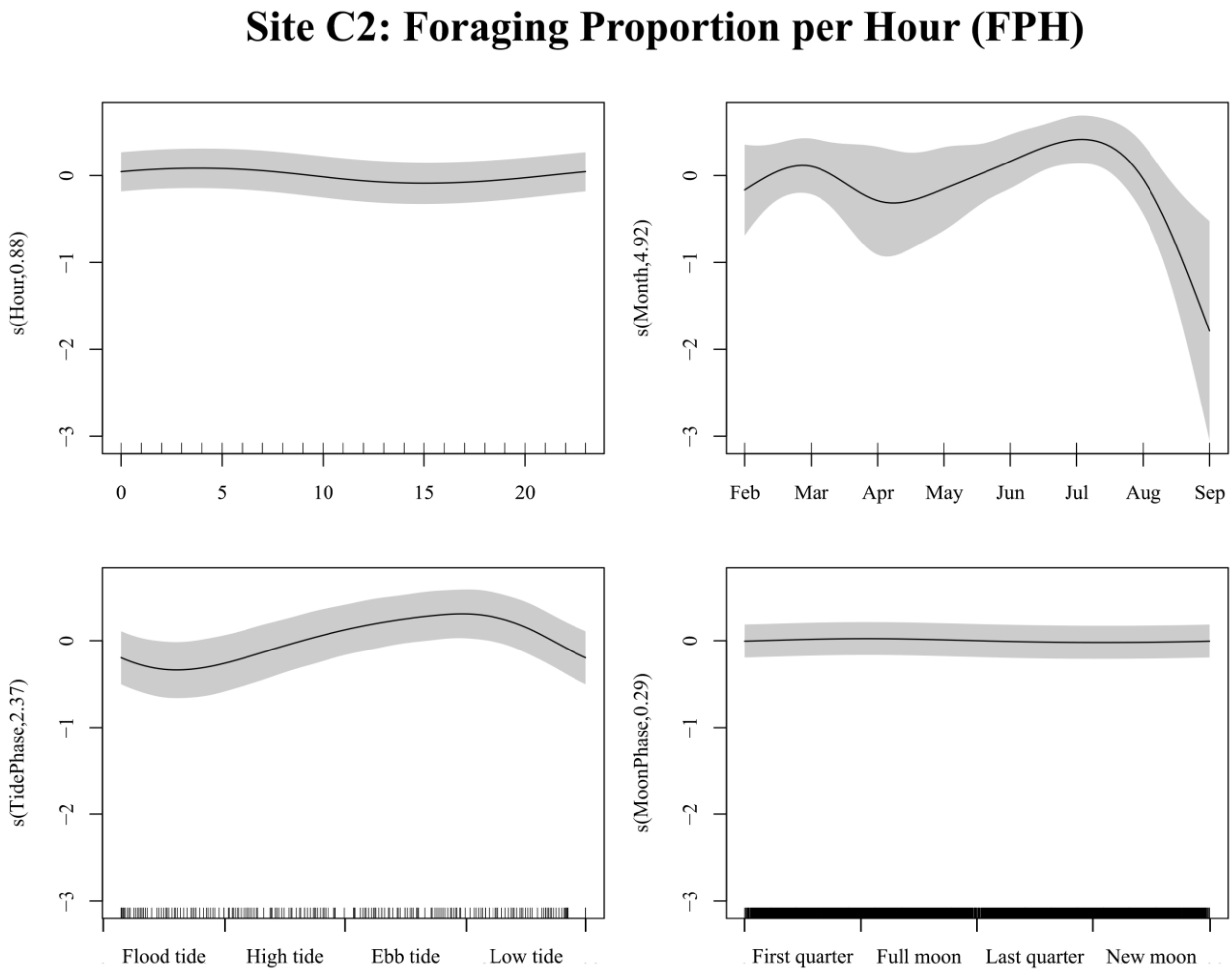


Figure 3.8 Generalised Additive Models (GAMs) outputs for the relationships between Foraging Proportion per Hour (FPH) and temporal and abiotic environmental factors observed from coastal odontocetes at C-POD deployment site C2 off Khanom, Nakhon Si Thammarat, Thailand during May – September 2019 and February – April 2020. The rug plots along the x-axis indicate the density of observations for each factor. The grey areas around the smoothed-plotted curves represent the 95% confidence intervals.

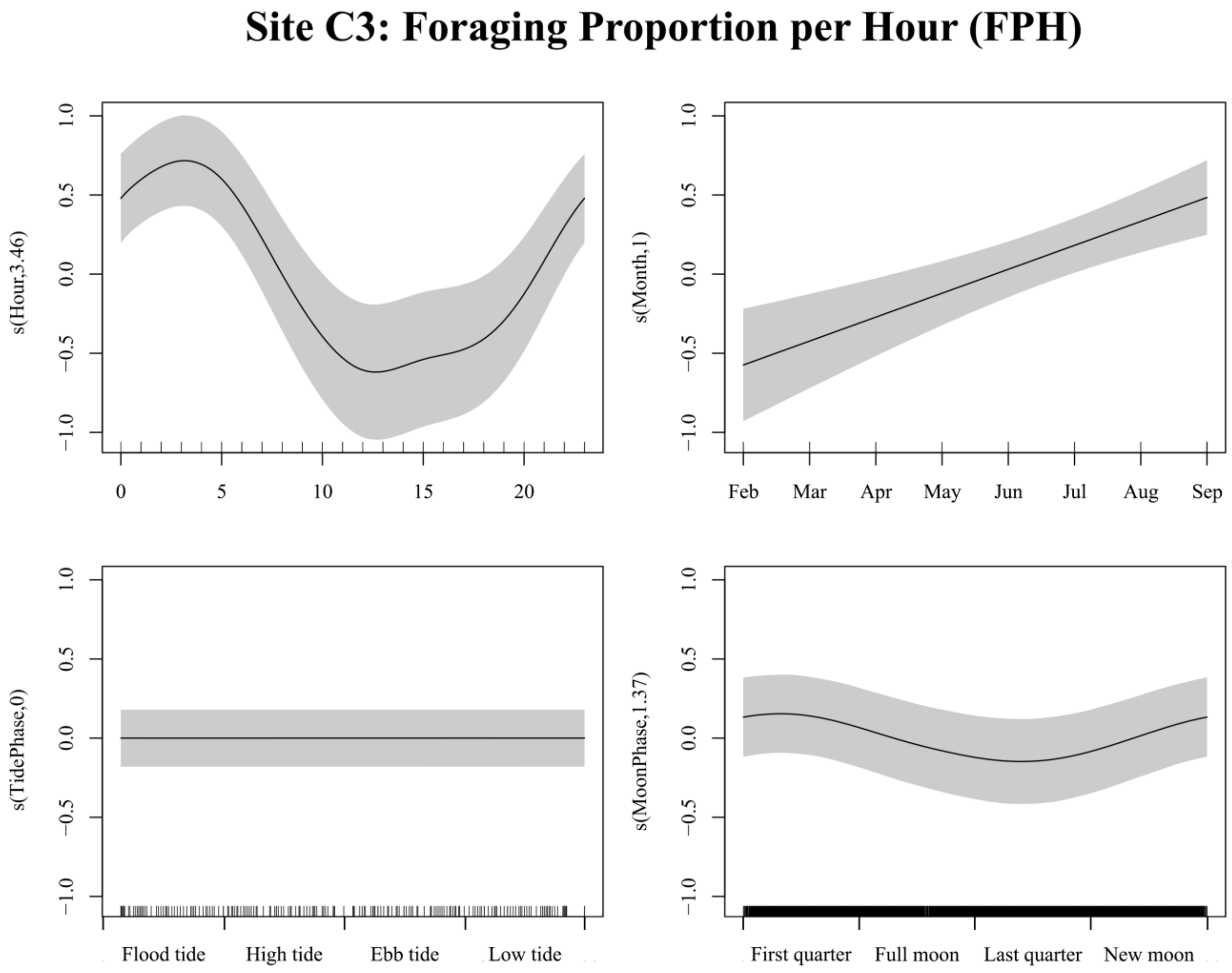

Site C3: Foraging Proportion per Hour (FPH)

Figure 3.9 Generalised Additive Models (GAMs) outputs for the relationships between Foraging Proportion per Hour (FPH) and temporal and abiotic environmental factors observed from coastal odontocetes at C-POD deployment site C3 off Khanom, Nakhon Si Thammarat, Thailand during May – September 2019 and February – April 2020. The rug plots along the x-axis indicate the density of observations for each factor. The grey areas around the smoothed-plotted curves represent the 95% confidence intervals.

3.5 | Discussion

This is the first study to be conducted using Passive Acoustic Monitoring (PAM) to investigate spatio-temporal variation potential influence of temporal and abiotic environmental factors on the occurrence and foraging occurrence of three sympatric coastal odontocete species (Irrawaddy dolphin, Indo-Pacific humpback dolphin and Indo-Pacific finless porpoise) off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand. The results of the study resonate to those from a previous boat-based study (Jutapruet et al. 2017). The level of occurrence measured by Detection Positive Minutes (DPM) at Laem Thuat Pier (site C1) and Taled Bay (site C2) were higher than at Thong Node Bay (site C3) supporting the overall 50% Kernel density estimation in Don Sak and Khanom waters (Jutapruet et al. 2017). Systematic PAM survey effort at larger spatial scales including western waters of Don Sak and southeastern waters of Khanom would eventually provide a more comprehensive overview of the distributions and habitat uses of the three odontocete species in the central-western Gulf of Thailand. Given that PAM is not limited by daylight availability and suitable sea state (Barlow et al. 2001; Nowacek et al. 2016), the methodology is recommended for future investigation. It would be further informative, if algorithms were developed that allowed separation of the three species in future application using PAM to investigate occurrence and foraging occurrence.

3.5.1 Laem Thuat Pier: the odontocete hub

Among the three C-POD deployment sites, Laem Thaut Pier had the highest levels of occurrence and foraging occurrence. Laem Thuat Pier had the highest levels of DPM and FPH among the three monitored sites and this was possibly influenced by the nutrient-rich water entering the area from the Don Sak River providing high productivity and availability of dolphin prey (Torregroza-Espinosa et al. 2020; Wang et al. 2019a). Odontocete prey availability is likely an important driver for the relatively high occurrence (mean DPM) and foraging occurrence (mean FPH) at the Pier. Freshwater run-off at the Don Sak River mouth causes accumulation of organic and inorganic material creating a nutrient-rich area and contributing to high marine productivity in the Pier area (Torregroza-Espinosa et al. 2020). The nutrient-loaded areas facilitates high phytoplankton productivity providing food for zooplankton (Wang et al. 2019a; Zhou et al. 2008) and ultimately for secondary consumers like molluscs and crustaceans and higher trophic level predator like fish (e.g. Family Mugilidae), which are the main prey for odontocete in the central-western Gulf of Thailand similar to what observed in other habitats (Barros et al. 2004; Parra & Jedensjö 2014).

3.5.2 Diel variation

The results showed that hour/diel cycle was a significant driver for the occurrence at all sites and for foraging occurrence at Laem Thuat Pier and Thong Node Bay. The level of echolocation activities was relatively higher during night-time (19:00 – 6:59 hr) compared to day-time (7:00 – 18:59 hr) at Laem Thuat Pier and Thong Node Bay. The higher level of foraging during hours of darkness (as indicated by FPH) at Laem Thuat Pier and Thong Node Bay indicate that prey may be more readily accessible at night. Higher occurrence and foraging occurrence during night-time have also been recorded in Indo-Pacific humpback dolphins in the Pearl River Estuary, China (Wang et al. 2015); common bottlenose dolphins (*Tursiops truncatus*) and harbour porpoise (*Phocoena phocoena*) in Cardigan Bay, Wales (Nuuttila et al. 2017b); and Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) and Indian Ocean humpback dolphins (*Sousa plumbea*) in the Menai Bay, Zanzibar, Tanzania (Temple et al. 2016). Additionally, higher illumination during day-time allow odontocetes to use both vision and echolocation to navigate, locate and identify objects/prey (Au 1993), whereas lower illumination during night-time makes odontocetes depend more on echolocation and may eventually lead to relatively higher echolocation rates during hours of darkness (Akamatsu et al. 1992; Nuuttila et al. 2017b; Wang et al. 2015). In other words, odontocetes may be present in the study area throughout day and night but produce less echolocation signals during the day when they instead may rely on vision to navigate and locate prey. This can explain why occurrence (DPM) and foraging occurrence (FPH) detected by PAM were higher during night-time.

3.5.3 Seasonal variation

Seasonal changes in prey occurrence may lead to seasonality in reproduction in common bottlenose dolphins (*T. truncatus*) in the Indian River Lagoon, Florida and in Texas, United States (Urian et al. 1996). Seasonal influences on the occurrence and foraging occurrence of the three species could not be fully investigated in this study due to lack of data during the winter monsoon season (October – January). Nevertheless, the results showed that month was a significant driver across all sites. Differences in monthly patterns shown by GAMs generally inferred that rainy (mid-May to September) had relatively higher levels of occurrence and foraging occurrence than summer (mid-February to mid-May) at all sites (except at Laem Thuat Pier), possibly due to lower dolphin-watching tourism activities in the rainy season (personal communication with the dolphin-watching tourism operators). Further fine-scaled investigation on predator-prey ecology in the central-western Gulf of Thailand or areas with similar tropical climate would provide more comparative aspects and more comprehensive overview of seasonal influences on local marine species.

3.5.4 Tidal variation

Overall, echolocation clicks were produced at higher level during ebb tide when tidal height was decreasing, while produced at lower level during flood tide when tidal height was increasing. There are no definite patterns between the occurrence level of echolocation clicks and tidal phase among odontocete species. Higher echolocation activities during ebb tide were reported in Indo-Pacific humpback dolphins in the in the Pearl River Estuary, China (Wang et al. 2015); and harbour porpoises off central Oregon, United States (Holdman et al. 2019) and in the Swansea Bay, Wales (Nuuttila et al. 2017a) — while higher echolocation activities during flood tide were reported in Indo-Pacific humpback dolphins in the Xin Huwei River Estuary, Taiwan (Lin et al. 2013); and common bottlenose dolphins in the Kessock Channel, Moray Firth, Scotland (Mendes et al. 2002). Tidal influences can affect prey distribution and consequently drive odontocete foraging activities (Fury & Harrison 2011; Guilherme-Silveira & Silva 2009). Odontocetes have a behavioural tendency for higher and more intense foraging activities during ebb and low tides (Guilherme-Silveira & Silva 2009; Wang et al. 2015), when lower water level and decreased water volume may concentrate prey in higher densities. This likely reduces the preys' possibility of escape and allows odontocetes to hunt more efficiently with a higher prey catch rates and lower trade-off of energy expenditure (Mendes et al. 2002; Wang et al. 2015) — especially in the very shallow areas (0.5 – 5.5 m depth) of Don Sak and Khanom. Hence, it is conceivable that odontocetes in the central-western Gulf of Thailand have developed their foraging strategies according to the tidal cycle.

3.5.5 Moon phase variation

Higher occurrence level of echolocation clicks during new moon and first quarter compared to other phases presented in the results might infer that odontocetes in the study area depended more on echolocation to locate prey and to navigate during lower moonlight conditions, whilst depended on both vision and echolocation due to increasing of moonlight during late first quarter, full moon and early last quarter. Similar pattern was reported in Indo-Pacific humpback dolphins in the Pearl River Estuary, China (Wang et al. 2015). This pattern was also evident in the current study, which showed lower level of echolocation activities during daylight hours. However, the GAM analyses showed variation and moon phase was a significant driver on occurrence but not significant on foraging occurrence (except at Laem Thuat Pier) indicating that further investigations are required to investigate moon phase as driver for odontocete occurrence and foraging occurrence more comprehensively. Moon phase has a direct effect on the level of illumination during the night which affects odontocetes' ability to use vision for navigation and prey detection, and hence likely affect the animals' relative reliance on echolocation (Benoit-Bird et al. 2009; Wang et al. 2015). Further, moon phase may have influences on odontocete foraging strategies capturing vertically migrating preys as reported in spinner dolphins (*Stenella longirostris*) in Hawaii, United States and dusky dolphins (*Lagenorhynchus obscurus*) off Kaikoura, New Zealand (Benoit-Bird et al. 2009). Vertical zooplankton migrants were found avoiding the surface during the full moon or high illumination phases (Pinot & Jansá 2001) and this may also create temporal patterns of prey availability for odontocetes.

3.5.6 Potential anthropogenic threats and impact on odontocetes in the central-western Gulf of Thailand

Coastal constructions, notably with the use of pile driver, can create noise disturbance which can cause displacement of odontocete occurrence (Bailey et al. 2010; Dähne et al. 2013; Leunissen et al. 2019), alteration in foraging and resting behaviours (Piwetz et al. 2021), increasing of stress (Erbe et al. 2018; Southall et al. 2007), damage in auditory system and temporary hearing loss (Kastelein et al. 2015; Leunissen & Dawson 2018; Southall et al. 2007). In Don Sak coastal water, construction using pile drivers for a port extension was observed at the Raja Ferry Port where Indo-Pacific humpback dolphins were often sighted from the boat-based surveys (Chapter 5). Evidence was shown that the population of Indo-Pacific humpback dolphins off Hong Kong were affected to some degree from coastal construction (Piwetz et al. 2021). However, it was not possible to investigate the occurrence and foraging occurrence of odontocetes near the construction areas because it was strongly suggested by the Don Sak subdistrict headman and community headmen not to deploy the C-POD within the ferry port's area to avoid being an obstacle to ferry traffic route. In the study area, there were two ferry companies (Raja Ferry and Seatran Ferry) operating and there was a total of 58 ferry trips per day within on the routes between Don Sak, Samui Island and Pha Ngan Island according to the companies' ferry timetables between May 2019 and April 2020. Further investigation is recommended to assess the potential noise disturbance due to coastal constructions on odontocetes off Don Sak and Khanom.

Beside coastal development projects, fisheries bycatch (i.e. gillnets entanglement) (Brownell Jr. et al. 2019), vessel strike (Schoeman et al. 2020), noise disturbance from motorised vessels (Bechdel et al. 2009) and boat-based dolphin-watching tourism activities (Christiansen et al. 2010) are potential anthropogenic threats for odontocete in the central-western Gulf of Thailand (Chapter 4) (Jutapruet et al. 2015). With the prevalence of boat-based activities in Don Sak and Khanom waters, this increases the risk for the animals to become exposed to those threats. Vessel strike, propeller cut and behavioural disturbance are likely to happen by speed boats from dolphin-watching tourism as these speed boats were regularly observed to violate the dolphin-watching guidelines (Adulyanukosol et al. 2012b) when approaching the animals (Chapter 4). It is therefore strongly recommended that future investigations should assess the impacts of anthropogenic activities on odontocetes as this would implement future conservation and management for odontocetes (Jefferson et al. 2009; Piwetz et al. 2021).

3.5.7 Recommendation in conservation and management

In conclusion, given that the occurrence and foraging occurrence are supported by the results from a previous study by Jutapruet et al. (2017), this study indicates that Laem Thuat Pier and Taled Bay should be considered as odontocete core habitats. Although Thong Node Bay showed relatively lower levels of occurrence and foraging occurrence than Laem Thuat Pier and Taled Bay, this area should also be monitored by future investigation to determine if it is qualified as another core habitat. Thus, it is proposed that the Department of National Park, Wildlife and Plant Conservation (DNP) and associated government organisations in the central-western Gulf of Thailand consider to establish marine protected areas (Gormley et al. 2012; Jefferson et al. 2009; Passadore et al. 2018) or expand the jurisdiction and protection boundary of marine national park to cover Laem Thuat Pier.

Temporal and spatial restrictions in the use of specific fishing gears such as crab gillnets (Chapter 2) may be necessary to reduce odontocete bycatch when the levels of occurrence and foraging occurrence are highest. This may be an effective and feasible way to reduce fisheries bycatch in the central-western Gulf of Thailand. Further, an enforced regulation for the boat-based dolphin-watching tourism to operate with minimum disturbance to occurrence and behaviours is recommended (Christiansen et al. 2010; Christiansen et al. 2013a).

Monitoring methodology is a vital component to management succession. PAM is recommended for future monitoring system because it is high-yield, spatio-temporally comprehensive, reliable, consistent, time efficient and cost effective. Ultimately, the spatio-temporal insights provided by this study represent a crucial starting point that will help to create effective conservation and management in the future. This will critically benefit endangered and vulnerable odontocete species in the central-western Gulf of Thailand where continuous expansion of anthropogenic activities are threatening their survival.

CHAPTER 4

Effects of Boat-Based Dolphin-Watching Tourism on the Surface Behaviours and Vocalisations of Indo-Pacific Humpback Dolphins (*Sousa chinensis*) off Don Sak, Surat Thani, Thailand

4.1 | Abstract

There is a growing concern regarding multiple threats from anthropogenic activities and their effects on short- and long-term health of coastal cetacean populations. This study investigated the potential effects of boat-based dolphin-watching tourism on the behaviour of Indo-Pacific humpback dolphins (*Sousa chinensis*) off Don Sak, Surat Thani, Thailand by comparing dolphin group surface behaviours and vocalisations when tourist boats were present (impact) and absent (control). Simultaneous shore-based dolphin group follows (n = 74) and passive acoustic monitoring of echolocation activity were conducted during 55 days between February and April 2020 at Laem Thuat Pier. Scan sampling methods were used to collect dolphin group surface behaviours and tourist boat activities, and a cetacean click recorder (F-POD) was used to collect dolphin acoustic activity. Dolphin behaviour/vocalisation budgets (proportion per day of different behaviours) and transitions (transition probability) between control and impact sessions were constructed and compared using Markov chain analyses. The results showed that dolphins significantly decreased the proportion of time spent resting (from 42% to 23%) and staying silent (from 79% to 71%), and significantly increased the proportion of time spent socialising (from 14% to 17%), travelling (from 3% to 22%) and producing regular clicks (from 18% to 26%) when tourist boats were present. As inferred from the Markov chain analyses, dolphins were more likely to start travelling and less likely to stay foraging, resting, socialising

and vocalising in the presence of tourist boats. This study demonstrates that the current boat-based tourism activity off Don Sak impact the short-term behaviours and vocalisations of Indo-Pacific humpback dolphins. The apparent changes in dolphin behaviours and vocalisations due to the presence of tourist boats may ultimately reduce dolphin fitness at both individual and population levels. The results highlight the need for management to minimise potential long-term negative effects on the dolphins and to ensure the sustainability of dolphin-watching tourism as an economic activity off Don Sak, Surat Thani, Thailand.

4.2 | Introduction

Cetacean-watching tourism has become one of the most economically important tourist activities worldwide in the past 30 years (Einarsson 2009; Higham et al. 2014; O'Connor et al. 2009). As a result of a rapid growth in the marine tourism industry and growing interest in observing marine wildlife in their natural environment, cetacean-watching tourism globally attracted over 13 million people in 119 countries and was valued at over USD 2.1 billion in 2008, with an estimated of 3,330 operators and 13,200 employees (O'Connor et al. 2009). Cetacean-watching tourism offers various benefits including: supporting local economies (Berggren et al. 2007), offering cetacean-research platforms (dos Santos & Bessa 2019; Hoyt 2001), promoting public awareness and support for marine conservation (Chen 2011; Duffus & Dearden 1993), elevating visitors' attitude toward marine environment (García-Cegarra & Pacheco 2017; Orams 1997), and representing an alternative to whaling as a potential sustainable use of marine resources (Einarsson 2009; Hoyt 1993).

However, serious concerns have been raised regarding cetacean welfare since cetacean-watching tourism activities have become more aggressive and more interactive toward the animals (Bejder et al. 1999; Constantine et al. 2004; Spradlin et al. 2001; Steckenreuter et al.

2012). Cetacean watching guidelines (Garrod & Fennell 2004; Orams 1997) have been regularly violated by ubiquitous operators through the conduction of close-up observation, provisioning (i.e. providing food for animals) and swim-with-cetaceans — instead of observation from a safe and appropriate distance (Christiansen et al. 2010; Filby et al. 2014; Fiori et al. 2019). Such violations put cetaceans at risk of being disturbed, harassed and/or injured with potential individual and population level effects (Bejder et al. 2006; Filby et al. 2014; Nowacek et al. 2001). Studies from around the world have shown that cetacean-watching tourism may have a negative impact on the cetacean behaviour, reproductive success and survival (Christiansen et al. 2010; Constantine et al. 2004; Filby et al. 2014). Previous research have shown that exposure to cetacean-watching tourism may affect cetacean behaviour including: travelling direction (Argüelles et al. 2016), travelling speed (Nowacek et al. 2001), vocalisation (Nowacek et al. 2007), diving pattern (Stensland & Berggren 2007) and breathing rate (Janik & Thompson 1996); and may lead to decreasing foraging, socialising and resting time (Constantine et al. 2004; Steckenreuter et al. 2012; Williams et al. 2002) — with potential detrimental impact to cetacean welfare (Bejder et al. 2006; Christiansen et al. 2013a; Kassamali-Fox et al. 2020). Furthermore, cetacean-watching tourism increases the chance of vessel strike/collision involving cetaceans, which could lead to incidental mortality (Laist et al. 2001; Schoeman et al. 2020; Stone & Yoshinaga 2000). Management, regulation and enforcement are therefore needed to create a sustainable use of cetaceans (Gormley et al. 2012; Guerra & Dawson 2016).

Thailand is a well-known tourism destination and with 27 cetacean species inhabiting Thai waters, cetacean-watching tourism has grown in popularity among Thai and foreigner tourists during the past 20 years (Adulyanukosol et al. 2014; Mustika et al. 2017). Cetacean-watching tourism is offered in many provinces along the Gulf of Thailand and the Andaman Sea coasts but there are currently no statistics available regarding the number of operators and employees or the socio-economic contribution to local economies or the annual GDP. The majority of the operators are local small-scale fishers, and boat-based cetacean-watching tourism has become an alternative source of income and a part-time livelihood for Thai coastal communities (Jutapruet et al. 2015; Mustika et al. 2017).

Central-western Gulf of Thailand is one of the most popular destinations for dolphin-watching tourism in Thailand including the coastal areas of Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat. The activity attracts approximately 10,000 tourists per year to the region (Mustika et al. 2017) and it is operated by approximately 120 boats from 10 communities on the mainland and approximately 20 boats from nearby island communities (e.g. Samui, Pha Ngan and Nok Taphao Islands). Dolphin-watching tourism occurs throughout the year with a high season in summer (March – May) and low season during monsoon season (October – January).

The central-western Gulf of Thailand is generally a shallow coastal habitat where Indo-Pacific humpback dolphins (*Sousa chinensis*) are resident year-round (Jutapruet et al. 2017). The Indo-Pacific humpback dolphin is listed as a Vulnerable species by the IUCN Red List (Jefferson et al. 2017) and the species is widely distributed in coastal areas across the Indian Ocean and Western Pacific Ocean (Jefferson & Karczmarski 2001), and ubiquitously distributed along the Gulf of Thailand and the Andaman Sea (Adulyanukosol et al. 2014). Census surveys in the central-western Gulf of Thailand estimated that the abundance of the Indo-Pacific humpback dolphins was 193 (95% CI: 167 – 249) in coastal waters off Don Sak in 2013 (Jutapruet et al. 2015) and 49 individuals (no reported 95% confidence intervals) off Khanom in 2009 (Jaroensutasinee et al. 2010).

A number of marine anthropogenic activities occur in the central-western Gulf of Thailand, particularly off Don Sak that may affect the health of Indo-Pacific humpback dolphins, including dolphin-watching tourism, fisheries, shipping, ferry traffic, factories and continuous expansion of coastal development projects to accommodate ferry ports, hotels/resorts/homestays (Jutapruet et al. 2015). Yet, there is currently no management regarding these activities to minimise disturbance to cetaceans. Furthermore, there is very limited understanding in general of the potential effects of anthropogenic factors on the occurrence and behaviours of cetaceans in the central-western Gulf of Thailand.

Passive Acoustic Monitoring (PAM) allows fine-scale study of vocalisations produced by cetaceans by recording, analysing and monitoring their acoustic activities, particularly the echolocation click trains. PAM has been demonstrated worldwide for its efficiency in studying cetacean occurrence (Campbell et al. 2017), foraging activities (defined in previous studies as echolocation click trains with inter-click intervals < 10 ms) (Nuuttila et al. 2013; Temple et al. 2016), distribution and habitat use (Dähne et al. 2013; Elliott et al. 2011) at large temporal scales with consistent and comparable data (Chelonia.co.uk 2020). PAM application creates minimal disturbance to cetaceans and their natural behaviours (Roberts & Read 2014). Furthermore, PAM's performance and effectiveness are not significantly affected by daylight, visibility, weather, sea state, surface glare, animal surface presence and observer bias, which hamper most traditional visual cetacean surveys (Barlow et al. 2001; Nowacek et al. 2016). While PAM may allow researchers to obtain insights about cetacean occurrence and behaviour that is possible from visual survey (Nowacek et al. 2016), limitations in classification algorithms could hinder species-specific identification for some cetacean species (Rasmussen & Miller 2002; Rasmussen et al. 2002), especially in areas inhabited by several cetacean species.

Bearing in mind that the visual surveys may be limited by extrinsic factors (Barlow et al. 2001; Nowacek et al. 2016) and may not provide data/information on submerged activities (e.g. foraging, social behaviour and vocalisation), visual surveys have been extensively demonstrated as an efficient and effective research platform for observing cetaceans and providing insights including occurrence (Karczmarski et al. 1999), distribution (Jutapruet et al. 2017), population size (Jutapruet et al. 2015), abundance (Poh et al. 2016) and behaviour (Würsig et al. 2015). Visual data collection has also been used to investigate how cetacean-watching tourism may affect surface behaviours of animals (Christiansen et al. 2010; Filby et al. 2014; Kassamali-Fox et al. 2020; Schuler et al. 2019).

This study provides the first investigation on the potential effects of boat-based dolphin-watching tourism on cetacean behaviour and vocalisation in Thailand using concurrent shore-based observations and PAM data collection. Data were analysed to investigate if the presence and level of dolphin-watching tourism boats and their interactions with Indo-Pacific humpback dolphins affect dolphin surface behaviours and vocalisations.

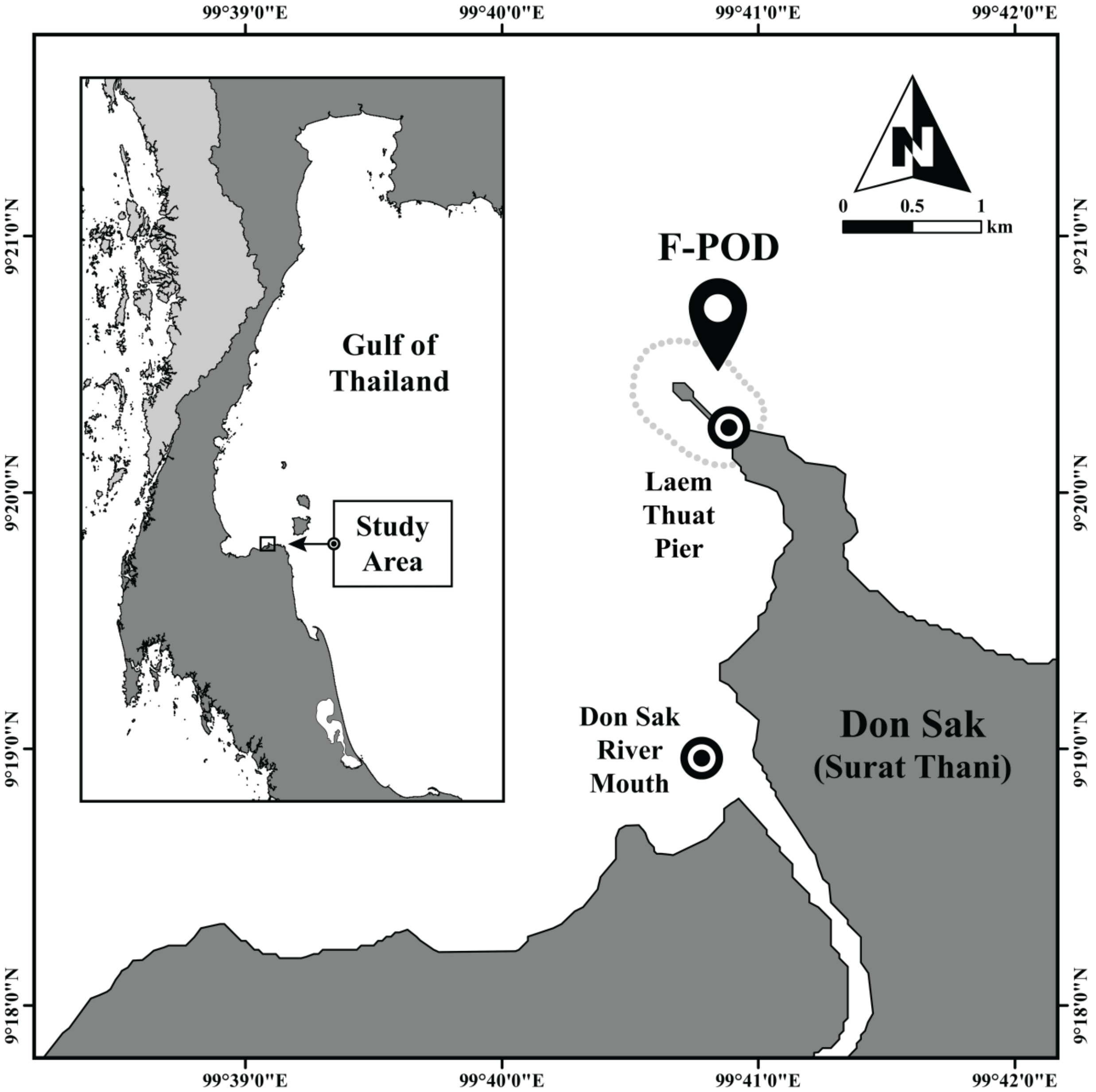


Figure 4.1 Locations where shore-based observation and passive acoustic monitoring were conducted to assess the effects of boat-based dolphin-watching tourism on the behaviours of Indo-Pacific humpback dolphins (*Sousa chinensis*) at Laem Thuat Pier, Don Sak, Surat Thani, Thailand during February – April 2020. The grey dots around the Pier indicate the area covered by shore-based observations.

4.3 | Methods

4.3.1 Study site

The study was conducted during 55 days between 11 February and 6 April 2020 at Laem Thuat Pier, Don Sak, Surat Thani, Thailand (Figure 4.1). The Laem Thuat Pier is 425 m long with a 5 m elevation above sea level, which provided an unobstructed 270° view of the study area covering approximately 0.4 km^2. The sea area around the pier is shallow with 0.5 – 7.0 m water depth (measured using a portable Hondex-PS7 depth sounder) and a mud bottom substrate.

Dolphin-watching tourism off Don Sak was conducted from 7:00 – 12:00 hr, but occasionally extended to 14:00 hr. The tourist boats were either typical long-tailed boats used by local fishers and dolphin-watching tour operators or speed boats exclusively used by operators from hotels/resorts/homestays on Samui Island and other nearby islands as part of marine tourism programmes.

4.3.2 Data collection

4.3.2.1 Shore-based observation

Shore-based data collection was conducted during daytime hours (07:00 – 15:00 hr). Focal group follows (Altmann 1974) were used to observe and record dolphin surface behaviours. This study defined a group of Indo-Pacific humpback dolphins as an assembly of two or more adult dolphins where each individual was within 10 m of another dolphin using a 10-m chain rule (Smolker et al. 1992). Only one dolphin group was followed at a time, but presence of any other dolphin groups within the study area were also recorded. Only behaviours displayed by adults were recorded since those of calves were considered dependent of their mothers.

Data were sampled every five minutes. At the beginning of each designated sampling time, the first behaviour displayed at the surface by each dolphin group member was recorded. Dolphin group behaviour was determined based on the behaviour displayed by the majority (defined as > 50%) of animals in the group. If two or more behaviours were equally observed, the first displayed behaviour was selected as the dolphin group behaviour. Dolphin group surface behaviours were determined and recorded using four predefined behavioural states (Table 4.1): Foraging (FOR), Resting (RES), Socialising (SOC) and Travelling (TRA). In addition, data were also collected on: dolphin group size, movement direction and speed; number of tourist boats present, type of boat, distance between boats and dolphin groups, and duration of the interaction; and Beaufort Sea State. All data were verbally recorded in real time using a Tascam DR-05X voice recorder to maintain the continuity of the visual observations.

Interactions between dolphin groups and tourist boats were defined as one or more tourist boats present within a 100-m radius of a dolphin group (Christiansen et al. 2010; Constantine et al. 2004; Stensland & Berggren 2007). The distance between a dolphin group and tourist boats was visually measured by estimating the number of boat lengths (one boat length = 10 m) between the dolphin groups and the boats. The group follows ended when the dolphin group was no longer present in the pier area or when the weather condition was unsuitable for data collection (Beaufort Sea State ≥ 3).

4.3.2.2 Passive acoustic monitoring

Passive acoustic data were collected using an echolocation click recorder (F-POD) (Chelonia.co.uk 2020) deployed 200 m off Laem Thuat Pier (9°20'27.5"N and 99°40'50.1"E) for 53 days from 14 February to 6 April 2020 (Figure 4.1). The F-POD was deployed at 1.5 m above the sea floor (Figure 4.2).

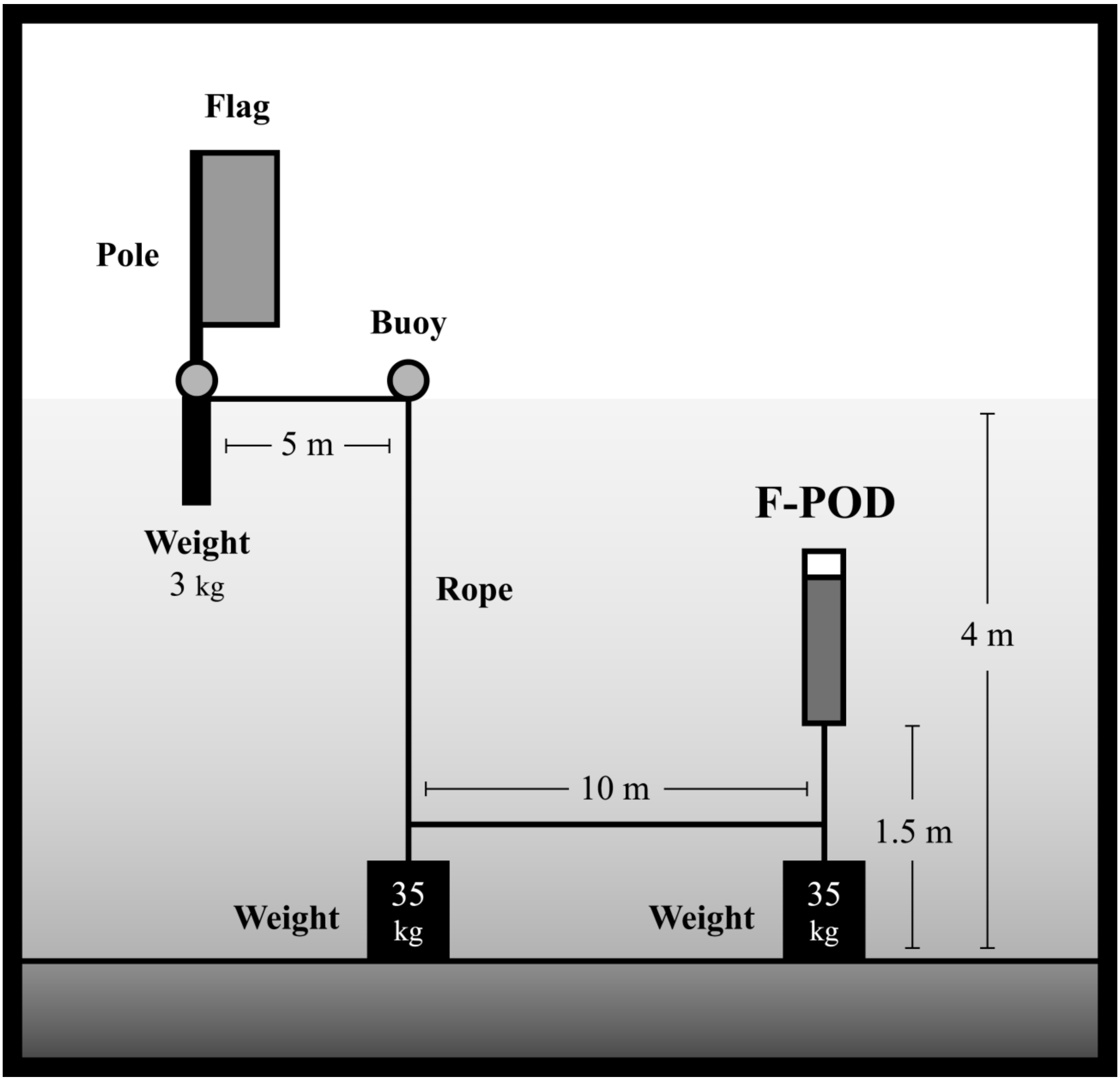


Figure 4.2 F-POD deployment set-up for passive acoustic monitoring at Laem Thuat Pier, Don Sak, Surat Thani, Thailand during February – April 2020

4.3.3 Data analysis

4.3.3.1 Visual and acoustic data processing

This study analysed simultaneously (every 5 min) collected acoustic data from the F-POD and visual data collected from the shore-based observations. The acoustic data were processed and analysed using the F-POD software, FPOD.exe (Version 1.0.2.01) (Chelonia Limited, Cornwall, UK: www.chelonia.co.uk). The KERNO-F classifier was used to distinguish the odontocete echolocation click trains from other sound sources. Dolphin click trains were classified into an “Other cet” group, while porpoise click trains were classified into a “NBHF” group. Only “Other cet” click trains of high and moderate quality were used in the analyses because “NBHF” click trains were likely produced by Indo-Pacific finless porpoises (*Neophocaena phocaenoides*) occasionally occurring in the study area. To date, the F-POD software does not include algorithms to acoustically differentiate the clicks between those produced by Indo-Pacific humpback dolphins and Irrawaddy dolphins (*Orcaella brevirostris*). To address this, we only analysed the “Other cet” click trains detected when only Indo-Pacific humpback dolphins were present in the study area based on the synchronously collected visual data from the shore-based observations. The time series of “Other cet” click trains were exported from the F-POD software for further analyses. Click trains with < 6 clicks were discarded from the analyses to reduce the number of false positives that may be generated by non-odontocete sound producing sources (Lin et al. 2013; Wang et al. 2019b).

Table 4.1 Behavioural states, vocal states and definitions observed from Indo-Pacific humpback dolphins (*Sousa chinensis*) at Laem Thuat Pier, Don Sak, Surat Thani, Thailand during February – April 2020. Behavioural states and definitions were modified from Christiansen et al. (2010).

Behavioural state	**Definition**
Foraging (FOR)	Rapid surfacing, frequent directional changes, chasing fish, leap feeding, peduncle diving and tail-out diving
Resting (RES)	Slow surfacing, logging, drifting and low activity level
Socialising (SOC)	Rubbing, petting, touching, mounting, chasing, circling, playing, genital inspections and other physical contacts between individuals
Travelling (TRA)	Persistent and directional movement with constant speed
Vocal state	**Definition**
Foraging buzzes (FB)	Echolocation clicks with ≥ 4.87% of foraging proportion
Regular clicks (RC)	Echolocation clicks with < 4.87% of foraging proportion
Silence (SX)	No echolocation activity

The acoustic data were analysed based on the minimum inter-click interval (ICI) and categorised into three vocal states: Foraging buzzes (FB), Regular clicks (RC) and Silence (SX, no clicks recorded) (Table 4.1). The minimum recorded ICIs ranged from 0.005 to 128 ms. Further analysis of the proportions of the echolocation ICI data indicated that these had a bimodal distribution, with two potential different functions that could be referred to as “Buzz ICI” indicative of foraging and “Regular ICI” indicative of regular click trains used for e.g. navigation (Pirotta et al. 2014). Gaussian Mixture Models (GMM) were used to further analyse the distribution of the data using “mixtools” package (Benaglia et al. 2009) in R Studio (Version 1.3.959) (R Core Team 2020). All minimum ICI data were normalised by natural log-transformation and fitted into the GMM via the Expectation Maximisation (EM) algorithms (Pirotta et al. 2014). The number of component distributions “k” was set to “2.” Then each data point (echolocation click train) was classified into one of the two functions (“Buzz ICI” or “Regular ICI”) based on the maximum probability calculated from the EM algorithms. The result is presented in Figure 4.3 which shows that the data were classified into two component distributions categorised based on the minimum ICIs, where the lower ICI distribution (“Buzz ICI”) proportion of all recorded clicks represented 4.87%. The 4.87% proportion was applied as an objective measure to determine whether a 5 min acoustic sample should be assigned as period representative of dolphin occurrence or dolphin foraging occurrence.

Finally, to investigate the potential effects of dolphin-watching tourism boats on dolphin surface behaviours and vocalisations, the data were arranged into two sessions: “Control” and “Impact”. The control sessions were defined as periods with absence of tourist boats, whereas the impact sessions were defined as periods with presence of at least one tourist boat. Potential significant difference in dolphin group size between control and impact sessions was tested using Mann-Whitney U test (Mann & Whitney 1947).

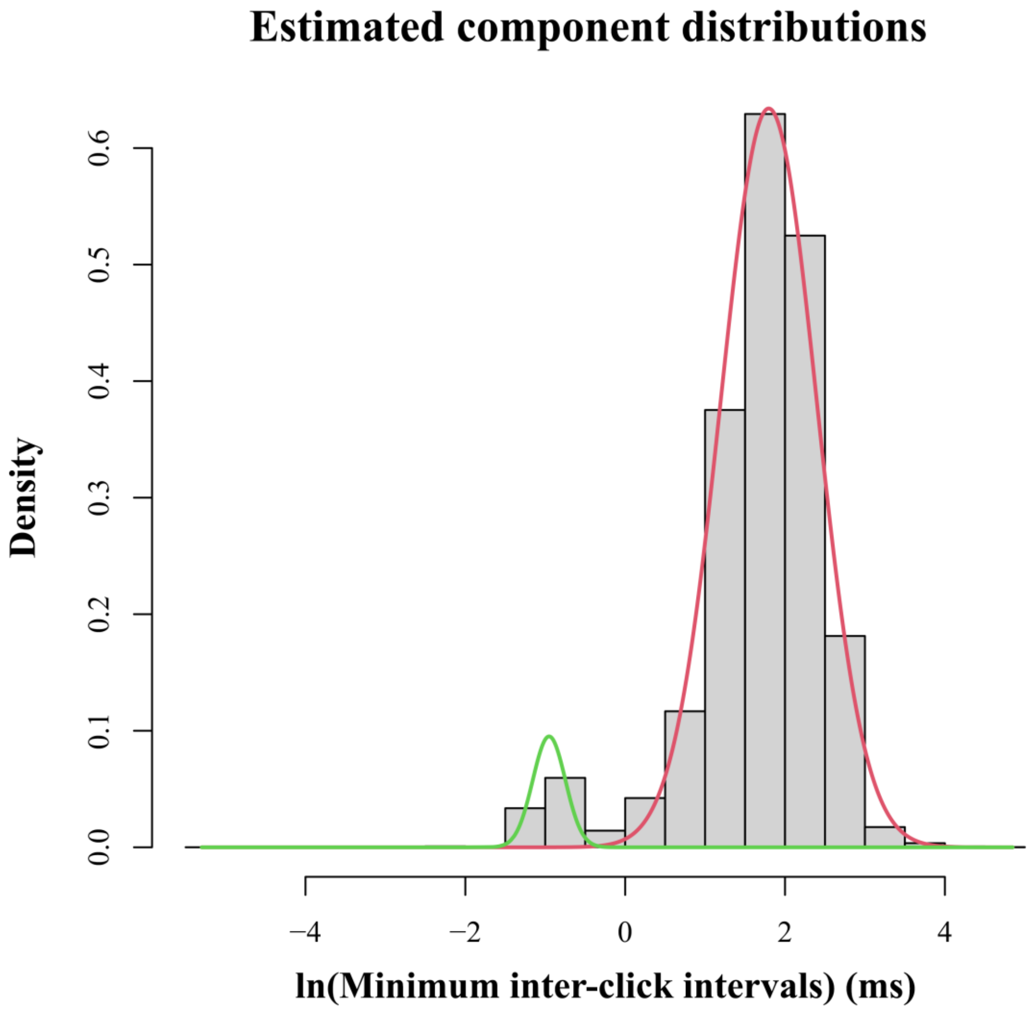


Figure 4.3 Component distributions estimated by Gaussian Mixture Models (GMM) for inter-click interval (ICI) time series produced by Indo-Pacific humpback dolphins (*Sousa chinensis*) at Laem Thuat Pier, Don Sak, Surat Thani, Thailand during February – April 2020. The first component distribution (green line) corresponds to the “Buzz ICI” and the second component distribution (red line) corresponds to the “Regular ICI.”

4.3.3.2 Behaviour and vocalisation budgets

The mean proportion (% per day with 95% confidence intervals) of time dolphins spent in each of the four behavioural states (Foraging, Resting, Socialising and Travelling) and the three vocal states (Foraging buzzes, Regular clicks and Silence), respectively, were calculated to create separate behaviour/vocalisation budgets for control and impact sessions using the formula:

$$PR = \sum_{i=1}^{n} P_i / N$$

where PR (PR_{SBO} and PR_{PAM}, respectively) = mean proportion (% per day); P_i = proportion (%) occurrence per day of each behavioural state / vocal state as observed from the shore-based observations (SBO) and PAM, respectively; N = total number of observation / PAM days. To test the effects of the tourist boats on the behaviour / vocalisation budgets, we compared the control and impact behaviour / vocalisation budgets using Goodness-of-fit test (Pearson 1900) and Two-proportion Z-test (Fleiss et al. 1981). Each behavioural state / vocal state in the control budget was statistically compared to its corresponding behavioural state / vocal state in the impact budget. All calculations and statistical analyses were performed in R Studio (Version 1.3.959) (R Core Team 2020).

4.3.3.3 Behaviour and vocalisation transitions

First-order time-discrete Markov chains (Guttorp & Minin 1995) were used to investigate the differences in transition probabilities between the preceding and the succeeding behavioural states / vocal states in control and impact sessions (Lusseau 2003a). Two separate contingency tables were constructed of preceding versus succeeding behavioural states / vocal states for each sampling time for both control and impact sessions. This provides an example of how preceding and succeeding behavioural states / vocal states were determined: the focal dolphin group was observed for 15 minutes from 9:03 to 9:17 hr and three behavioural states were recorded: Foraging, Resting and Travelling at 9:05, 9:10 and 9:15 hr, respectively. Here, the first transition comprised of Foraging (9:05 hr) as preceding behavioural state and Resting (9:10 hr) as succeeding behavioural state; and the second transition comprised of Resting (9:10 hr) as preceding behavioural state and Travelling (9:15 hr) as succeeding behavioural state.

Then the transition probabilities from preceding to succeeding behavioural states / vocal states were calculated for both control and impact contingency tables using the formula (Lusseau 2003a):

$$P_{ij} = a_{ij} \Big/ \sum_{j=1}^{n} a_{ij} , \sum_{j=1}^{n} P_{ij} = 1$$

where P_{ij} = transition probability from behavioural state / vocal state i to j in the Markov chains; i = preceding behavioural state/vocal state; j = succeeding behavioural state / vocal state; a_{ij} = number of transitions observed from behavioural state / vocal state i to j; and n = total number of behavioural states / vocal state. To test the effects of the tourist boats on the behaviour / vocalisation-transition probabilities, the control and impact contingency tables were compared using Goodness-of-fit test (Pearson 1900) and Two-proportion Z-test (Fleiss et al. 1981). Each behaviour / vocalisation-transition probability in the control contingency table was statistically compared to its corresponding behaviour / vocalisation-transition probability in the impact contingency table.

4.3.3.4 Cumulative behaviour and vocalisation budgets

The effects of dolphin-watching tourism levels (duration of the interaction with the tourist boats) on the dolphin behaviour and vocalisation budgets were investigated by comparing the differences between the cumulative behaviour / vocalisation budgets and the control behaviour/vocalisation budgets (Christiansen et al. 2010; Lusseau 2003a). The cumulative behaviour/vocalisation budgets were calculated using the formula (Christiansen et al. 2010; Lusseau 2003a):

$$CB = (A \times IMP) + (B \times CON)$$

where CB = cumulative behaviour / vocalisation budgets; A = proportion (ranging from 0 to 1) of time per day dolphins spent in impact session (tourist boats present); B = proportion (1 – A) of time per day dolphins spent in control session (tourist boats absent); IMP = impact behaviour / vocalisation budgets; and CON = control behaviour / vocalisation budgets. Next, we artificially varied the proportion of time (during daytime hours) per day dolphins spent with the tourist boats from 0 to 100% to investigate the corresponding *p*-value for each proportion of time. This allowed investigation of, at what dolphin-watching tourism level, the cumulative behaviour / vocalisation budgets may be significantly affected (Christiansen et al. 2010). For each behavioural / vocal state, the differences between the cumulative behaviour / vocal budget and the control behaviour / vocal budget were statistically tested using Two-proportion Z-test (Fleiss et al. 1981).

4.3.4 Ethical approval

This study has been approved by the Newcastle University Ethics Committee (reference number: 18871/2019) and the Animal Welfare and Ethical Review Body (AWERB), Newcastle University (AWERB Project ID number: ID 821).

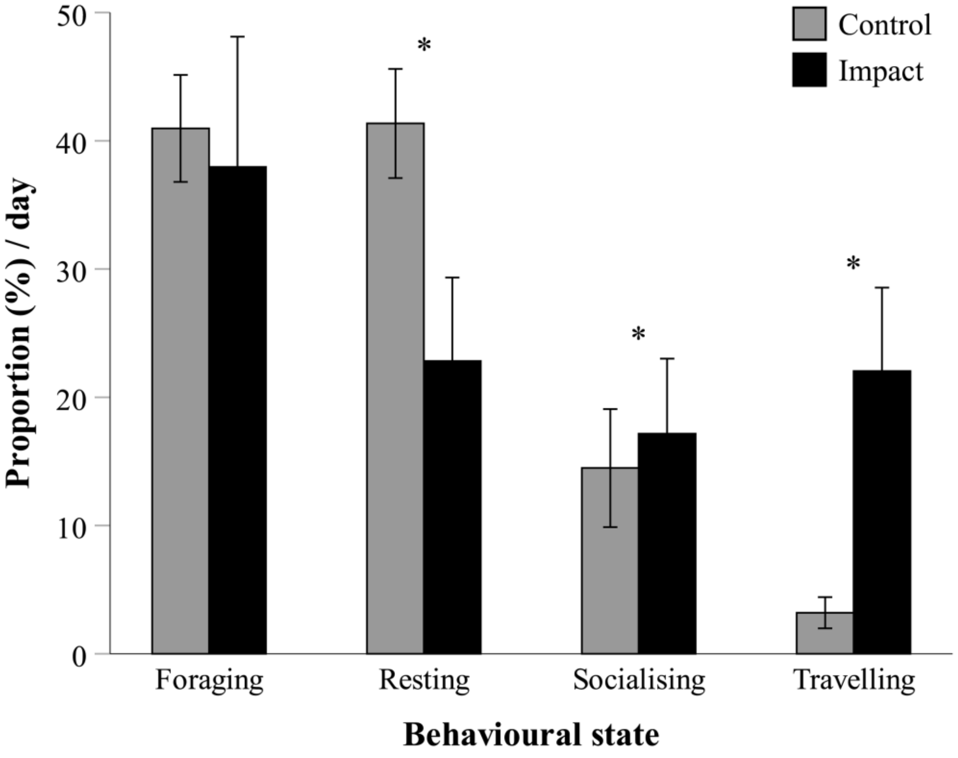
4.4 | Results

4.4.1 Dolphin group follow

From 278 hours of shore-based observation, 230 and 48 hours were spent observing control (tourist boats absent) and impact (tourist boats present) sessions, respectively. In total 74 groups of Indo-Pacific humpback dolphins were followed (21 and 53 during control and impact sessions, respectively). Mean durations of dolphin group follows were 122 minutes (95% CI: 87 – 157) and 54 minutes (95% CI: 42 – 65) for control and impact sessions, respectively. Dolphin median group size was 5 (95% CI: 4 – 5). There were no significant difference in dolphin group size between control and impact sessions (Mann-Whitney U test, U = 175.5, $p = 0.2795$). The median number of tourist boats interacting with the dolphin groups was 1 (range: 1 – 4). The mean time tourist boats interacted with the dolphins was 70 minutes (95% CI: 56 – 84). The mean distance between the tourist boats and the dolphins was 22 m (95% CI: 20 – 24).

4.4.2 Gaussian mixture models

Concurrent with the dolphin group follows, Passive Acoustic Monitoring (PAM) recorded 50,244 echolocation click trains. Gaussian Mixture Models (GMM) and Expectation Maximisation (EM) algorithms classified 47,912 and 2,332 click trains as “Regular ICI” and “Buzz ICI”, respectively. The GMM analysis showed that Indo-Pacific humpback dolphins off Don Sak produced foraging buzzes and regular clicks with mean minimum ICIs of 0.393 ms (95% CI: 0.390 – 0.396) and 7.139 ms (95% CI: 7.098 – 7.181), respectively.



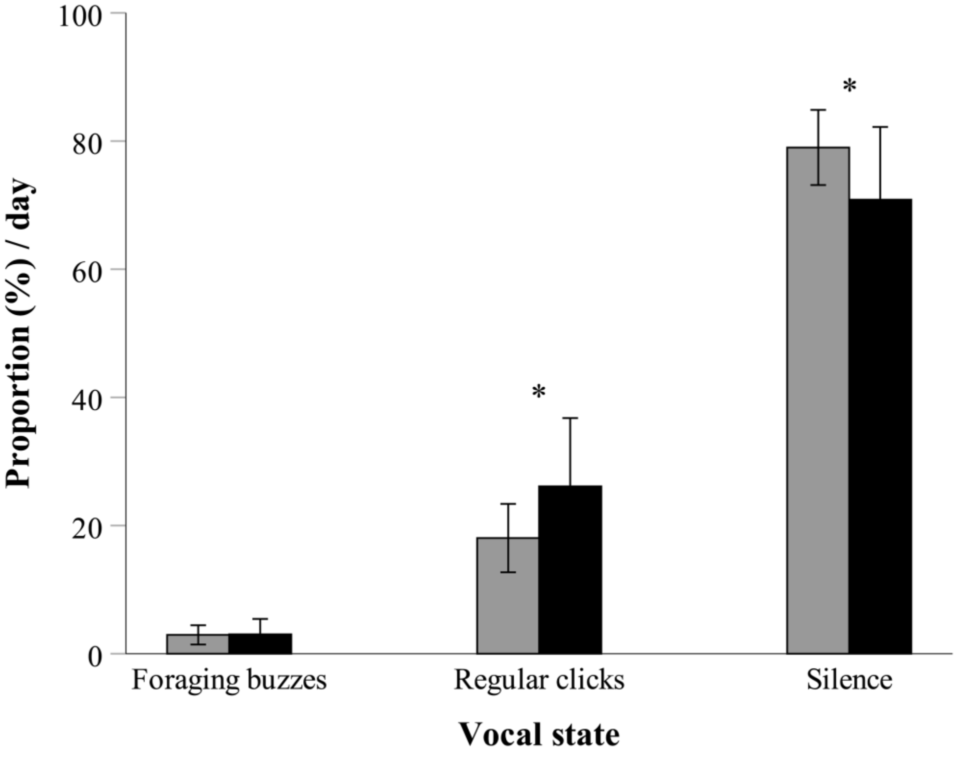


Figure 4.4 Behaviour budget and vocalisation budget of Indo-Pacific humpback dolphins (*Sousa chinensis*) activities: the proportion (%) of time spent per day in each behavioural state and vocal state during control (tourist boats absent) and impact (tourist boats present) sessions at Laem Thuat Pier, Don Sak, Surat Thani, Thailand during February – April 2020. Error bars represent 95% confidence intervals. (*) indicates behavioural state and vocal state with a significant difference ($p < 0.05$).

Table 4.2 Mean and Goodness-of-fit test outputs for behaviour budget and vocalisation budget between control and impact sessions observed from Indo-Pacific humpback dolphins (*Sousa chinensis*) at Laem Thuat Pier, Don Sak, Surat Thani, Thailand during February – April 2020

Behaviour budget							
Behavioural state	**Control mean (95% CI)**	**Impact mean (95% CI)**	χ^2	**Z**	**df**	***p*-value**	**Significance**
Foraging	41 (37 – 45)	38 (28 – 48)	3.46	1.86	1	0.0628	No
Resting	42 (37 – 46)	23 (16 – 29)	81.13	9.01	1	< 0.0001	Yes
Socialising	14 (10 – 19)	17 (11 – 23)	13.25	3.64	1	0.0003	Yes
Travelling	3 (2 – 4)	22 (16 – 29)	277.99	16.67	1	< 0.0001	Yes
Vocalisation budget							
Vocal state	**Control mean (95% CI)**	**Impact mean (95% CI)**	χ^2	**Z**	**df**	***p*-value**	**Significance**
Foraging buzzes	3 (1 – 4)	3 (1 – 5)	0.018	0.13	1	0.8932	No
Regular clicks	18 (13 – 23)	26 (15 – 37)	4.167	2.04	1	0.0412	Yes
Silence	79 (73 – 85)	71 (59 – 82)	4.177	2.04	1	0.0409	Yes

4.4.3 Behaviour budget

Dolphins spent 41%, 42%, 14% and 3% of their time foraging, resting, socialising and travelling, respectively during control session — and 38%, 23%, 17% and 22% of their time foraging, resting, socialising and travelling, respectively during impact session (Figure 4.4 and Table 4.2). Dolphin behavioural states were significantly affected by the tourist boats (Goodness-of-fit test, $\chi^2 = 270.99$, df = 3, $p < 0.0001$). Dolphins significantly decreased the proportion of time spent resting (from 42% to 23%; Z-test, Z = 9.01, $p < 0.0001$) and significantly increased the proportion of time spent socialising (from 14% to 17%; Z-test, Z = 3.64, $p = 0.0003$) and travelling (from 3% to 22%; Z-test, Z = 16.67, $p < 0.0001$) (Figure 4.4 and Table 4.2).

4.4.4 Vocalisation budget

Dolphins spent 3%, 18% and 79% of their time producing foraging buzzes, regular clicks and staying silent, respectively during control session — and 3%, 26% and 71% of their time producing foraging buzzes, regular clicks and staying silent, respectively during impact session (Figure 4.4 and Table 4.2). Dolphins significantly increased the proportion of time producing regular clicks (from 18% to 26%; Z-test, Z = 2.04, $p = 0.0412$) and significantly decreased the proportion of time staying silent (from 79% to 71%; Z-test, Z = 2.04, $p = 0.0409$) during impact session (Figure 4.4 and Table 4.2). However, there was no difference in the proportion of time dolphins produced foraging buzzes between impact and control sessions (from 3% to 3%; Z-test, Z = 0.13, $p = 0.8932$) (Figure 4.4 and Table 4.2).

4.4.5 Behaviour transition

The Markov chain analyses showed 16 types of behaviour transitions with corresponding transition probabilities between control and impact sessions (Figure 4.5 – 4.6 and Table 4.3). The presence of and interaction with the tourist boats had significant impact on the transition probabilities of the dolphin behavioural states (Goodness-of-fit test, $\chi^2 = 430.15$, df = 15, $p < 0.001$). Eight of the possible 16 types of behaviour transitions were significantly affected by the tourist boats during impact session (Figure 4.5 – 4.6 and Table 4.3). Five behaviour transitions significantly increased during impact sessions: Foraging → Travelling (Z-test, Z = 6.96, $p < 0.001$); Resting → Socialising (Z-test, Z = 2.81, $p = 0.0049$); Resting → Travelling (Z-test, Z = 9.44, $p < 0.001$); Socialising → Travelling (Z-test, Z = 2.56, $p = 0.0103$) and Travelling → Travelling (Z-test, Z = 2.83, $p = 0.0047$) — and three behaviour transitions significantly decreased during impact sessions: Foraging → Resting (Z-test, Z = 4.96, $p < 0.001$); Resting → Resting (Z-test, Z = 3.95, $p = 0.0001$) and Socialising → Resting (Z-test, Z = 2.38, $p = 0.0171$) (Figure 4.5 – 4.6 and Table 4.3).

Dolphins were likely to stay travelling or change their preceding behavioural states to travelling during impact sessions (Figure 4.5 – 4.6 and Table 4.3): Foraging → Travelling (2% to 11%), Resting → Travelling (2% to 20%), Socialising → Travelling (3% to 9%) and increased the proportion of Travelling → Travelling (32% to 55%). Dolphins that were resting were also likely to start socialising during impact sessions (Figure 4.5 – 4.6 and Table 4.3): Resting → Socialising (9% to 17%). In contrast, dolphins were less likely to stay resting or change their preceding behavioural state to resting during impact sessions (Figure 4.5 – 4.6 and Table 4.3): Foraging → Resting (34% to 16%), Resting → Resting (57% to 38%) and Socialising → Resting (30% to 17%).

4.4.6 Vocalisation transition

The Markov chain analyses showed nine types of vocalisation transitions with corresponding transition probabilities between control and impact sessions (Figure 4.5 – 4.6 and Table 4.3). The presence of and interaction with the tourist boats had no significant impact on the transition probabilities of dolphin vocalisations (Goodness-of-fit test: $\chi^2 = 7.739$, df = 8, $p = 0.4594$). None of the possible nine types of vocalisation transitions were significantly affected by the tourist boats during impact sessions (Figure 4.5 – 4.6 and Table 4.3).

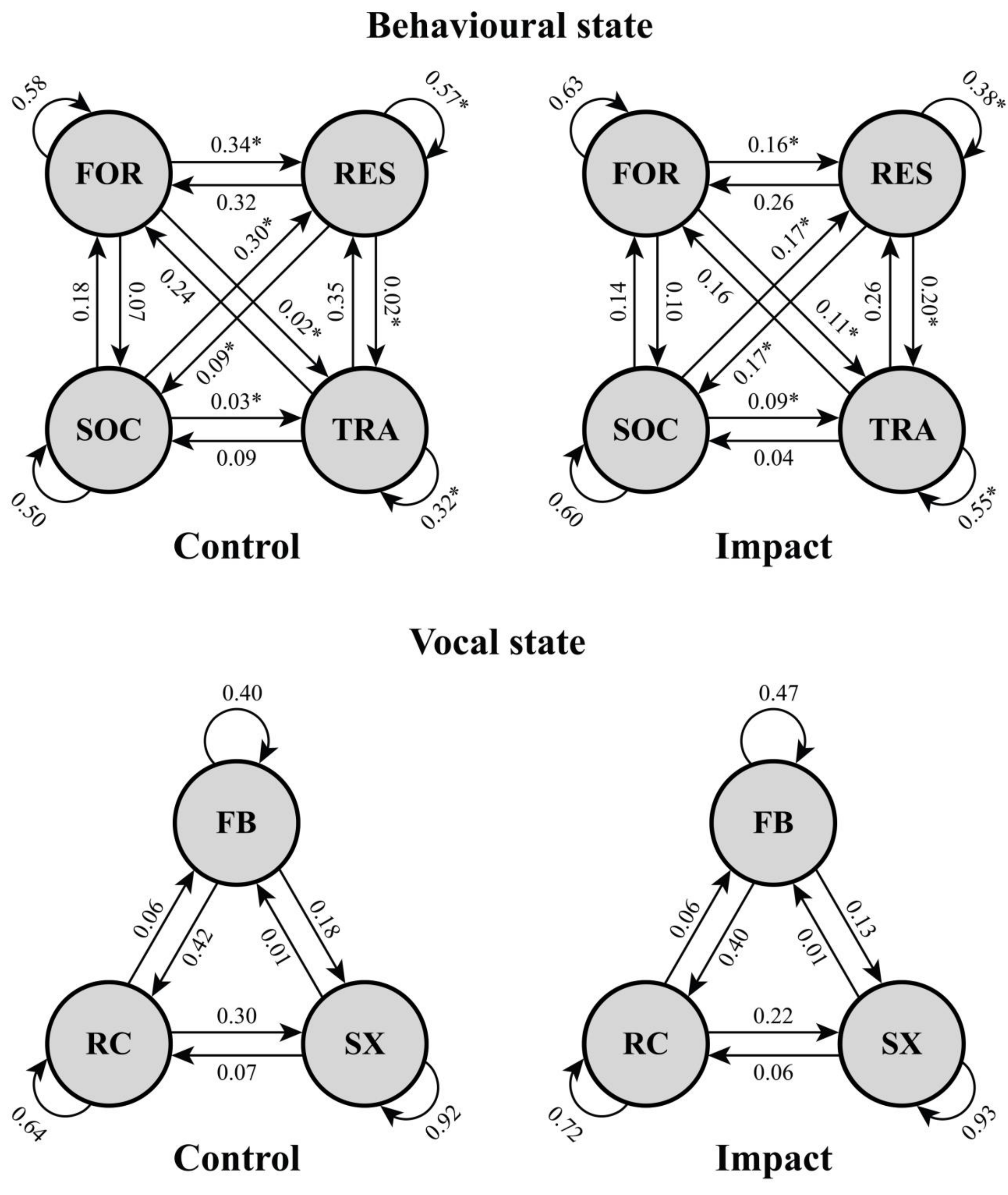
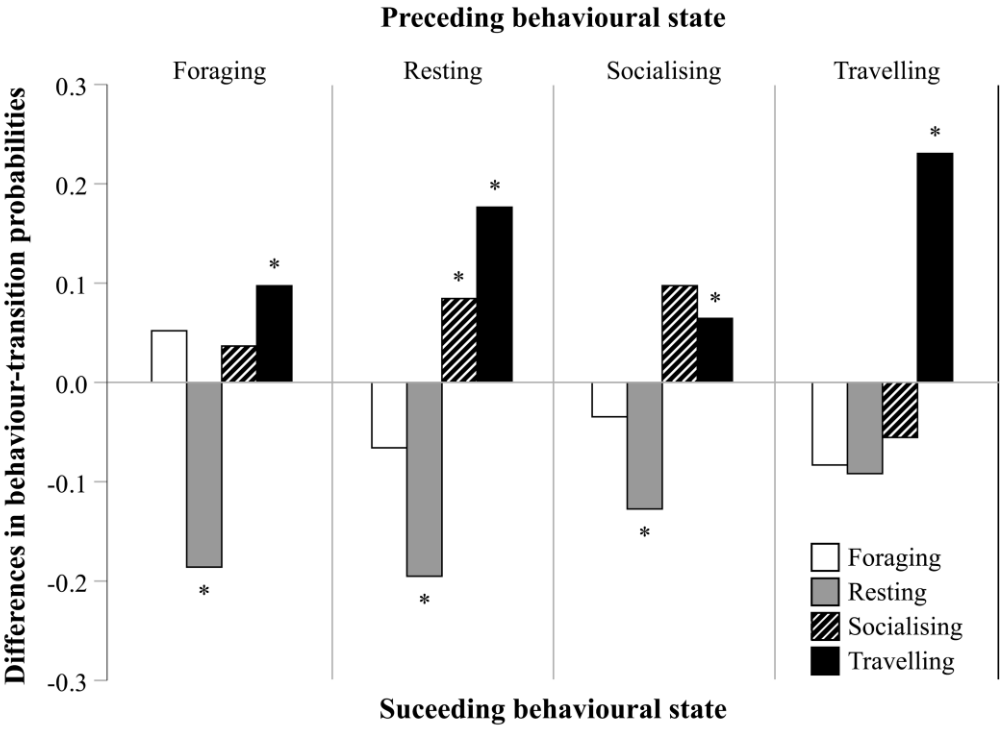


Figure 4.5 Markov chains representing behaviour-transition probabilities and vocalisation-transition probabilities of Indo-Pacific humpback dolphins (*Sousa chinensis*) during control (tourist boats absent) and impact (tourist boats present) sessions at Laem Thuat Pier, Don Sak, Surat Thani, Thailand during February – April 2020. Behavioural states: FOR (Foraging), RES (Resting), SOC (Socialising) and TRA (Travelling). Vocal states: FB (Foraging buzzes), RC (Regular clicks) and SX (Silence). Each number represents a value of transition probability. (*) indicates a transition probability with a significant difference ($p < 0.05$).



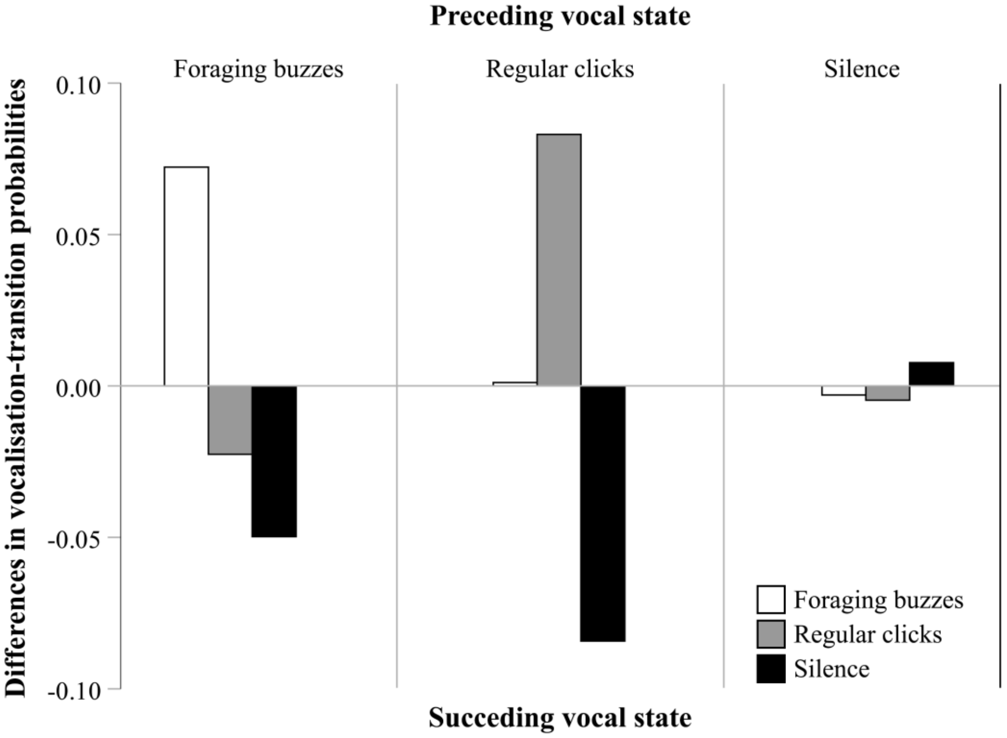
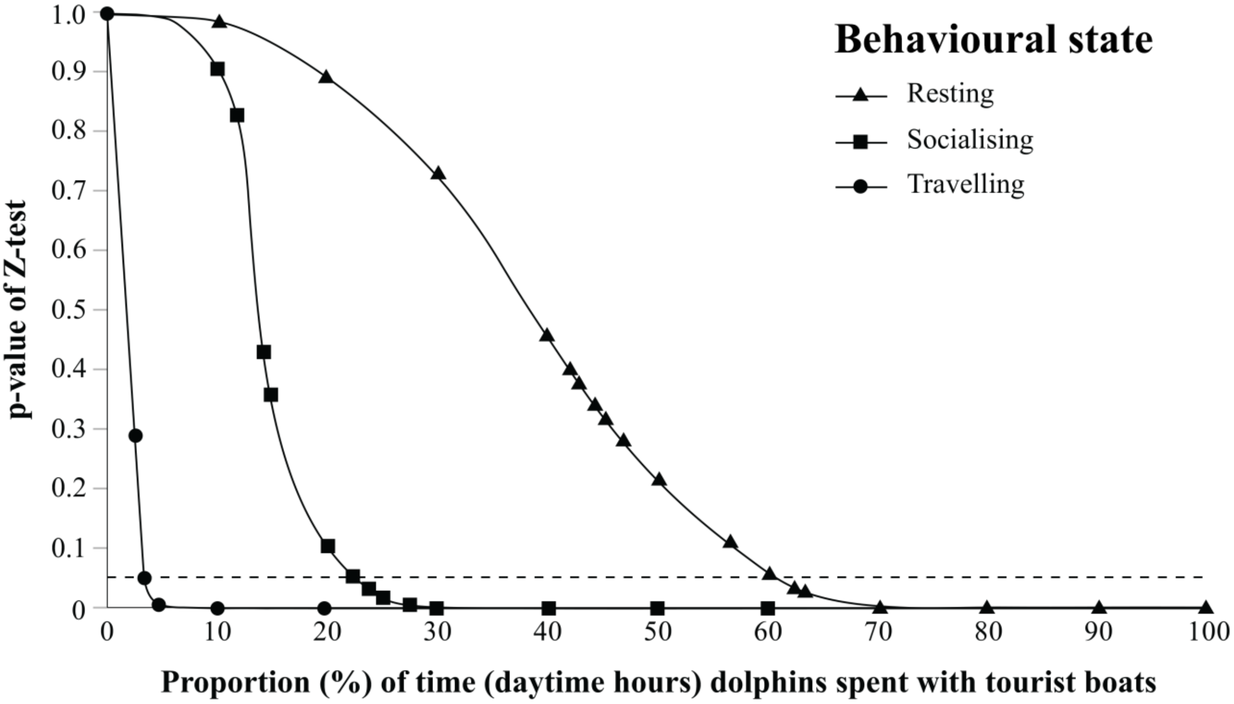


Figure 4.6 Differences ($P_{ij(Impact)} - P_{ij(Control)}$) in behaviour-transition probabilities and vocalisation-transition probabilities of Indo-Pacific humpback dolphins (*Sousa chinensis*) activities between control (tourist boats absent) and impact (tourist boats present) sessions at Laem Thuat Pier, Don Sak, Surat Thani, Thailand during February – April 2020. Vertical lines separate each preceding behavioural state. The bars represent the succeeding behavioural states and vocal states (see legend). (*) indicates a transition probability with a significant difference ($p < 0.05$).

Table 4.3 Probabilities and two-proportion Z-test outputs for behaviour transition and vocalisation transition between control and impact sessions observed from Indo-Pacific humpback dolphins (*Sousa chinensis*) at Laem Thuat Pier, Don Sak, Surat Thani, Thailand during February – April 2020

Behavioural state (Preceding → Succeeding)	$P_{ij(Control)}$	$P_{ij(Impact)}$	**P difference** (Impact – Control)	χ^2	**Z**	**df**	***p*-value**	**Significance**
FOR → FOR	0.58	0.63	0.05	1.57	1.25	1	0.2109	No
FOR → RES	0.34	0.16	-0.18	24.62	4.96	1	< 0.0001	Yes
FOR → SOC	0.07	0.10	0.03	2.72	1.65	1	0.0992	No
FOR → TRA	0.02	0.11	0.09	48.46	6.96	1	< 0.0001	Yes
RES → FOR	0.32	0.26	-0.06	1.84	1.35	1	0.1754	No
RES → RES	0.57	0.38	-0.19	15.57	3.95	1	0.0001	Yes
RES → SOC	0.09	0.17	0.08	7.91	2.81	1	0.0049	Yes
RES → TRA	0.02	0.20	0.18	89.19	9.44	1	< 0.0001	Yes
SOC → FOR	0.18	0.14	-0.04	0.43	0.66	1	0.5117	No
SOC → RES	0.30	0.17	-0.13	5.68	2.38	1	0.0171	Yes
SOC → SOC	0.50	0.60	0.10	2.54	1.59	1	0.1110	No
SOC → TRA	0.03	0.09	0.06	6.58	2.56	1	0.0103	Yes
TRA → FOR	0.24	0.16	-0.08	1.37	1.17	1	0.2418	No
TRA → RES	0.35	0.26	-0.09	1.29	1.14	1	0.2563	No
TRA → SOC	0.09	0.04	-0.05	1.50	1.22	1	0.2214	No
TRA → TRA	0.32	0.55	0.23	8.00	2.83	1	0.0047	Yes

Vocal state (Preceding → Succeeding)	$P_{ij(Control)}$	$P_{ij(Impact)}$	**P difference** (Impact – Control)	χ^2	**Z**	**df**	***p*-value**	**Significance**
FB → FB	0.394	0.467	0.073	0.0523	0.23	1	0.8191	No
FB → RC	0.423	0.400	-0.023	1.39E-30	1.18E-15	1	1.0000	No
FB → SX	0.183	0.133	-0.050	0.0076	0.09	1	0.9306	No
RC → FB	0.062	0.063	0.001	1.79E-31	4.23E-16	1	1.0000	No
RC → RC	0.638	0.721	0.083	2.3472	1.53	1	0.1255	No
RC → SX	0.300	0.216	-0.084	2.6911	1.64	1	0.1009	No
SX → FB	0.008	0.005	-0.003	0.0790	0.28	1	0.7786	No
SX → RC	0.066	0.061	-0.005	0.0514	0.23	1	0.8207	No
SX → SX	0.926	0.934	0.008	0.1753	0.42	1	0.6755	No



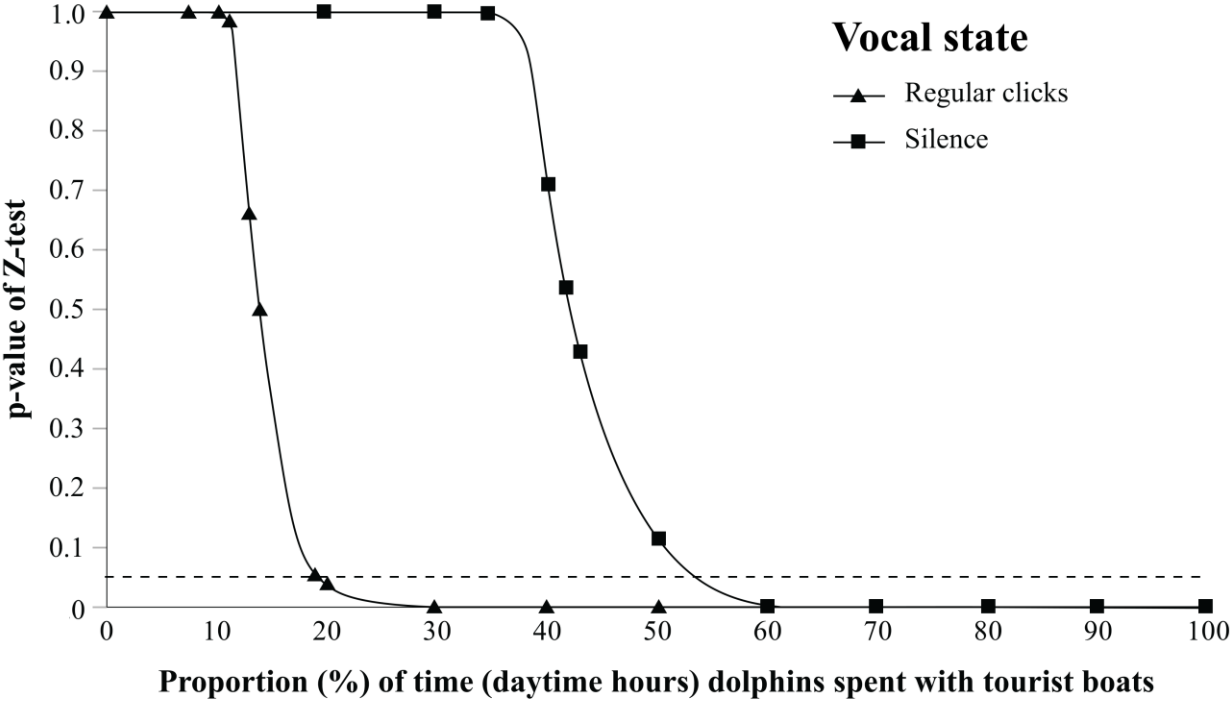


Figure 4.7 The *p*-value of the difference between cumulative and control behaviour budgets, and cumulative and control vocalisation budgets of Indo-Pacific humpback dolphins (*Sousa chinensis*) at Laem Thuat Pier, Don Sak, Surat Thani, Thailand during February – April 2020. Each curve represents different behavioural and vocal states (see legends). Dash line indicates the statistical level of significance ($p < 0.05$).

4.4.7 Cumulative behaviour budget

The duration of time dolphins spent with the tourist boats had significant impact on three cumulative behaviour budgets at different levels (Figure 4.7). The cumulative behaviour budgets for Resting, Socialising and Travelling were significantly affected if dolphins spent 60%, 22% and 4% of daytime hours per day with the tourist boats, respectively (Figure 4.7). This shows that tourism intensity of 4% (19 minutes) per day (7:00 – 15:00 hr) is sufficiently long to affect the cumulative behaviour budget of the dolphins off Don Sak.

4.4.8 Cumulative vocalisation budget

The duration of time dolphins spent with the tourist boats had significant impact on two cumulative vocalisation budgets at different levels (Figure 4.7). The cumulative vocalisation budgets of Regular clicks and Silence were significantly affected if dolphins spent 19% and 53% of the daytime hours per day with the tourist boats, respectively (Figure 4.7). This shows that a tourism intensity of 19% (91 minutes) per day (7:00 – 15:00 hr) is sufficiently long to affect the cumulative vocalisation budget of the dolphins off Don Sak.

4.5 | Discussion

4.5.1 Synchronisation of visual and acoustic data

This study is the first in Thailand to investigate the effects of boat-based dolphin-watching tourism on cetacean surface behaviours and vocalisations using synchronously collected visual and acoustic data. Previous research in other areas that have assessed effects of boat-based tourism on dolphin behaviour have used visual data of surface behaviour in relation to different levels of tourism activities (Cecchetti et al. 2018; Christiansen et al. 2010). However, visual observations are limited by various extrinsic factors (Barlow et al. 2001; Nowacek et al. 2016) and do not provide data on the acoustic behaviour of the animals and potential impact on their echolocation, and communication signals from boat activities (Au 2009). The present study demonstrates the efficacy and feasibility of using PAM and visual observations to collect complementary data for more comprehensive assessment of the potential impact from tourism activities, where PAM detected variations of echolocation activities and visual observations simultaneously provided dolphin surface behaviours in response to boat-based tourism. Using synchronous visual and acoustic data may therefore provide better understanding of the anthropogenic effects on cetaceans in future research.

4.5.2 Classification criterion using acoustic parameter for foraging activities

To acoustically identify potential foraging activities, previous studies used an inter-click interval (ICI) threshold of 10 ms to classify foraging buzzes from other echolocation signals (Leeney & Elwen 2011; Nuuttila et al. 2013). However, the mean minimum ICIs of foraging buzzes (0.39 ms) and regular clicks (7.14 ms) produced by Indo-Pacific humpback dolphins off Don Sak were lower than reported for other odontocete species e.g. common bottlenose dolphins (*Tursiops truncatus*) in the Moray Firth, Scotland (4 ms of mean buzz ICIs) (Pirotta et al. 2014) and in the Cardigan Bay, Wales (134 ms mean minimum ICIs) (Nuuttila et al. 2013); Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in the Koombana Bay, Bunbury, Australia (63 ms mean ICIs) (Wahlberg et al. 2011); and franciscana dolphins (*Pontoporia blainvillei*) in the Babitonga Bay, Brazil (10 ms mean minimum ICIs) (Paitach et al. 2021). This demonstrates that the ICIs of foraging buzzes and subsequently the classification criterion for foraging behaviours using acoustic parameters may differ depending on species and geographical areas. By fitting the acoustic data in a Gaussian Mixture Model (Pirotta et al. 2014) provided a more objective approach in this study to identify the threshold for foraging buzz ICIs from the resulting bimodal distribution. Further, our results showed that the Indo-Pacific humpback dolphins off Don Sak had a mean < 10 ms for the “Regular ICI” indicating that the < 10 ms ICIs used in other studies (Leeney & Elwen 2011; Nuuttila et al. 2013) may not be an appropriate level to identify foraging buzz ICIs depending on species and geographical area. It is therefore recommended that the species and area specific thresholds are identified in future research investigating foraging occurrence of echolocating odontocetes.

4.5.3 Concerns regarding dolphin-watching tourism levels

Boat-based dolphin-watching tourism occurs year-round in Don Sak, Surat Thani and in Khanom, Nakhon Si Thammarat with around 140 boats engaged in the activity operating in the dolphin core habitats (Jutapruet et al. 2015; Jutapruet et al. 2017). There were up to four boats simultaneously observed interacting with dolphins during the study, however, this can increase up to 20 – 30 boats during high season (March – May) in non-COVID-19 years (personal communication with local dolphin-watching tourism operators). Therefore, this study may represent a minimum amount of disturbance that the dolphins may experience in the area compared to the tourism activities during peak non-COVID times. The analysis of cumulative behaviour and vocalisation budgets showed a duration 19 and 91 minutes of tourist boat presence, respectively may significantly affect dolphin surface behaviours and vocalisations. The average length of the tourist boats interactions with the dolphin in this study was 70 minutes which exceeded the cumulative threshold/significant levels. Ultimately, the duration of 19 minutes can be used in a regulation as maximum interaction time for the dolphin-watching tourism activity to prevent negative effects. Given that 1 – 4 tourist boats were observed interacting with the dolphins per impact session and the level of dolphin-watching tourism presented in this study had significant impact on the dolphins, a full-scale activity of dolphin-watching tourism during non-COVID times would likely lead to increased levels of behavioural changes in the dolphins.

4.5.4 Effects of tourist boats on dolphin foraging

This study did not indicate any significant effect of the dolphin-watching tourism on the proportion of time dolphin spent foraging (based on the behaviour and acoustic data). However, the Markov chain analyses showed that foraging dolphins were likely to stop foraging and start travelling when the tourist boats were present. Previous research in other areas showed that dolphin foraging activities decreased when the tourist boats were present for common dolphins (*Delphinus* sp.) in the Hauraki Gulf (Stockin et al. 2008), the central and east coast Bay of Plenty, North Island, New Zealand (Meissner et al. 2015) and the southern coast of São Miguel, Azores, Portugal (Cecchetti et al. 2018); Indo-Pacific bottlenose dolphins off the south coast of Zanzibar, Tanzania (Christiansen et al. 2010); and common bottlenose dolphins in Bocas del Toro, Panama (Kassamali-Fox et al. 2020). Repetitive disruption of foraging activities can lead to long-term negative effects on dolphin welfare and survival at individual and population levels (Christiansen & Lusseau 2015; New et al. 2015). Reduction of time spent foraging may result in decreased food consumption and hence reduction in energy acquisition leading to nutritional deficiency for individuals (Christiansen et al. 2013b; Williams et al. 2006). Such conditions will therefore likely cause negative impacts on individual survival and reproductive success (Christiansen & Lusseau 2015; New et al. 2015) which will ultimately lead to the decline of populations (Bejder et al. 2006; Lusseau et al. 2006).

4.5.5 Effects of tourist boats on dolphin resting

Previous research has documented interruption or reduction in time cetaceans spend in resting behaviour in presence of tourist boats and watercrafts (Lundquist et al. 2012; Steckenreuter et al. 2012; Visser et al. 2011). This has been reported for: bottlenose dolphins (*Tursiops* spp.) in the Bay of Islands, New Zealand (Constantine et al. 2004), the south coast of Zanzibar, Tanzania (Christiansen et al. 2010) and Port Stephens, New South Wales, Australia

(Steckenreuter et al. 2012); Risso’s dolphins (*Grampus griseus*) off Pico Island, Azores, Portugal (Visser et al. 2011); Dusky dolphins (*Lagenorhynchus obscurus*) off Kaikoura, New Zealand (Lundquist et al. 2012); and spinner dolphins (*Stenella longirostris*) in the Southern Egyptian Red Sea, Egypt (Fumagalli et al. 2018). The results of the present study showed that the proportion of time spent resting by Indo-Pacific humpback dolphins off Don Sak was significantly affected by the tourist boats and further that the resting behaviour was interrupted and transitioned to other behaviours and primarily to travelling.

Resting is a fundamental behaviour and imperatively vital for animal welfare (Tyne et al. 2015). Disruption and reduction in resting activities by anthropogenic disturbances can reduce animal energy conservation (Williams et al. 2006) and induce physiological & metabolic stress (Dey et al. 2019; Fair & Becker 2000; Romero 2004), which can reduce the awareness and vigilance in dolphins and likely lead to increased predation risks (Frid & Dill 2002). Although odontocetes are top predators with limited predation risks in the central-western Gulf of Thailand based on lacks of shark scars on the dolphins, a chronic decrease in alertness and energetic reserves may put them under increased anthropogenic risks e.g. vessel strikes (Fair & Becker 2000; Schoeman et al. 2020). The behavioural disturbance caused by tourism activities may further lead to increased stress levels that also reduce or suppress the efficiency of the immune system (Fair & Becker 2000). It may further reduce nursing time and threaten the survival of dolphin offspring (Stensland & Berggren 2007). Recurrent disruption in resting may thus ultimately lead to a long-term negative impact on dolphin populations (Lusseau et al. 2006).

4.5.6 Effects of tourist boats on dolphin travelling

Dolphins significantly increased the time spent travelling when the tourist boats were present based on the observed changes in behaviour budgets and behaviour-transition probabilities. When dolphins were approached and followed at close distances (< 10 m) by the tourist boats, they were often observed leaping away from the approaching boats. A similar behaviour has also been observed in spinner dolphins in the Kealakekua Bay, Hawaii, USA (Bazua & Valiente 2008), where tourisms increased dolphin aerial activities. Further, dolphins were sometimes observed to conduct longer dives and changes in direction when surfacing to increase distance and to avoid approaching tourist boats, likely reflecting dolphins' vessel avoidance strategies (Nowacek et al. 2007; Piwetz et al. 2015). These behavioural patterns of vessel avoidance have also been reported in Indian Ocean humpback dolphins (*Sousa plumbea*) off the Algoa Bay, Eastern Cape, South Africa (Karczmarski et al. 1997); Indo-Pacific humpback dolphins off the coast of Lantau Island, Hong Kong (Ng & Leung 2003; Piwetz et al. 2012) and the Sanniang Bay, China (Li et al. 2015); and bottlenose dolphins (*Tursiops* sp.) in the Saratosa Bay, Florida, USA (Nowacek et al. 2001), the Doubtful Sound, New Zealand (Lusseau 2003b), the south coast of Zanzibar, Tanzania (Christiansen et al. 2010), the Lampedusa Island, Italy (La Manna et al. 2013; Papale et al. 2012) and Bocas del Toro, Panama (Kassamali-Fox et al. 2020). Horizontal avoidance and pro-longed dive times may be the only option in the study area in this study due to the shallow water depth. More travelling requires more energy (Noren et al. 2016; Williams et al. 2006) and where energy acquisition is reduced due to opportunity loss in foraging and resting, leading to higher energy demands (Noren et al. 2016).

4.5.7 Effects of tourist boats on dolphin vocalisations

The results further showed that Indo-Pacific humpback dolphins off Don Sak spent a lower proportion of time silent and a higher proportion of time producing regular clicks when tourist boats were present. Regular clicks are used by dolphins for navigation and/or to locate and avoid objects such as boats (Au 2009). The change in the acoustic behaviour is likely related to the increased travelling behaviour when tourist boats were present.

Odontocetes are sensitive to underwater noise (Erbe et al. 2018; Nowacek et al. 2007) and their behaviours may be disturbed by various anthropogenic sound generated by e.g. motorised vessel propulsion (Erbe 2002; Nowacek et al. 2007; Piwetz et al. 2012). Nevertheless, previous research have shown that odontocete vocalisations decreased in the presence of vessel traffic as reported in common bottlenose dolphins in the Sado estuary, Portugal (Luís et al. 2014) and the Fremantle Inner Harbour, Western Australia, Australia (Marley et al. 2017); and Yangtze finless porpoises (*Neophocaena asiaeorientalis asiaeorientalis*) in the Yangtze River, China (Zhou et al. 2021). However, it is difficult to directly and acoustically compare the behavioural responses to anthropogenic noise-generating sources between different odontocete species in different habitats, because of a number of factors that may contribute to differences and variation in dolphin behavioural responses including: habituation or sensitisation to vessels & noises, source power & bandwidth, level of exposure, age & sex of dolphin, individual past experience and habitat characteristics (Erbe 2002; Perry 1998; Watkins 1986).

4.5.8 Effects of tourist boats on dolphin socialising

Interactions with the tourist boats significantly increased the time dolphins spent socialising. When tourist boats were present in the area, dolphins were often observed displaying physical contacts (e.g. rubbing and courtship) (Karczmarski et al. 1997). Increased socialising behaviours during tourism periods can also increase chance of vessel strikes (Laist et al. 2001; Martinez & Stockin 2013), especially for the calves that are likely inexperienced in how to avoid the vessels, which make them more vulnerable (Dwyer et al. 2014; Laist et al. 2001; Stone & Yoshinaga 2000). Habituation/desensitisation can reduce alertness and awareness of dolphins and may consequently increase the risk of accidental vessel strike (Martinez & Stockin 2013; Nowacek et al. 2007; Stone & Yoshinaga 2000).

4.5.9 Concerns regarding potential vessel strike

Behavioural interruptions are not the only threats to the Indo-Pacific humpback dolphins off Don Sak or in the central-western Gulf of Thailand. Vessel strike/collision and propeller cuts (Schoeman et al. 2020; Stone & Yoshinaga 2000; Wells et al. 2008) can potentially be great threats to the dolphins. All tourist boats showed low level of compliance to the available cetacean-watching guidelines (Adulyanukosol et al. 2012b) by usually approaching the dolphins at close range (1 – 10 m) with their engines running. Dolphins were regularly followed (or chased) by the tourist boats, especially the speed boats with the distances < 10 m. This was perhaps intentional to impress the tourists who also expected to see and take photos of the dolphins up close. Watercrafts were regularly observed travelling and cutting through the dolphin groups or near the groups (1 – 5 m) at full speed. These watercrafts included dolphin-watching tourism boats; small-scale and commercial fishing vessels; speed boats for dolphin-watching and marine tourisms; and jet skis for recreational activities. Dolphins showed indications of habituation towards vessels, as they were occasionally observed to continue surfacing without any changes in direction or speed while the tourist boats approached at close distance. This may consequently reduce animals' vigilance to the approaching vessels (Nowacek et al. 2007; Stone & Yoshinaga 2000).

Given the large number of operating tourist boats in Don Sak and Khanom waters (140 boats) with up to 20 – 30 boats reported simultaneously interacting with dolphins during high season, this likely increases the chance of accidents (e.g. vessel strike and propeller cut) to happen (Bechdel et al. 2009; Dwyer et al. 2014; Schoeman et al. 2020). However, there are no records of vessel strikes in Don Sak and none was observed during the study. However, some of the observed dolphins had injuries on their body, dorsal fin and flukes, which could possibly have been caused by boat propellers.

4.5.10 Ideas for mitigation and prospective policy

To reduce the pressure from boat-based dolphin-watching tourism on the dolphins with minimal impact on the economic benefits to the local communities, it is proposed that the number of tourist boats entering the areas, boat speed, dolphin-approaching distance should be restricted, regulated, assessed and monitored (Adulyanukosol et al. 2012b; Berggren et al. 2007; Wu et al. 2020). It is recommended that, certified dolphin-watching tour operators and boat captains (who have passed a dolphin-watching teaching programme/examination and are licensed) should be the only operators allowed to conduct dolphin tourism activities. There should be at least one authorised officer at the Pier: to monitor all daily dolphin-watching boat activities and to press charges against any tour operator violating the proposed regulation e.g. by when chasing or approaching animals at close distance (< 30 m) and providing food or swimming with animals. In addition, information boards/brochures should be provided to introduce and help tourists understand how to behave when being on the tour boats. Reduction of dolphin-boat interactions would minimise disturbance to the animals (Guerra & Dawson 2016; Wu et al. 2020) and the duration of 19 minutes should ultimately be used in the Thai dolphin-watching regulation as maximum interaction time. Further, “holidays” should be given to dolphins i.e. periods when no tourist boats are allowed (Berggren et al. 2007).

Watercrafts for recreational purposes such as jet skis and speed boats should be strictly prohibited and regulated in the pier area to minimise potential vessel strike incidence and disturbance. When regulations are violated, appropriate prosecution should be implemented. Alternatively, as dolphins can be clearly observed from the pier, coin-operated binoculars and/or guided tours, where the visitors pay for information about dolphins, can be ways to support dolphin-watching activities without disturbing the animals on the water.

As presented in this study, the changes in short-term surface and acoustic behaviours caused by the current intensity of dolphin-watching tourism off Don Sak are a cause for concern and if continued may lead to long-term effects on individual fitness (survival and reproduction) (Christiansen & Lusseau 2015; New et al. 2015), which ultimately could lead to population effects/decline (Bejder et al. 2006; Lusseau et al. 2006). The results of the study highlight the need for management to minimise potential long-term negative effects on the dolphins and to ensure the sustainability of dolphin-watching tourism as an economic activity off Don Sak, Surat Thani, Thailand.

CHAPTER 5

Abundance Estimate of Indo-Pacific Humpback Dolphins (*Sousa chinensis*) off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand

5.1 | Abstract

Indo-Pacific humpback dolphins (*Sousa chinensis*) in Thai coastal waters are threatened by anthropogenic activities due to rapid coastal expansion during the past decades. In order to facilitate status assessment of Indo-Pacific humpback dolphins in Thailand, it is imperative to generate abundance estimates for the species distribution range. This can then be used together with information on anthropogenically caused mortality and disturbance to assess species viability. In this study, boat-based surveys were conducted during May – July 2019 off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand, to collect photo-identification (photo-ID) data to generate a new abundance estimate for Indo-Pacific humpback dolphins. Capture-recapture analyses of the photo-ID data resulted in an estimate of 52 (95% CI: 49 – 62) non-calf individuals. The cumulative identification of the dolphins in the study area indicated that most animals present during the study were sampled. Given the relatively small abundance estimate and the ongoing anthropogenic threats, conservation and management actions are recommended to prevent potential extirpation of the species in the study area.

5.2 | Introduction

Cetaceans are threatened globally by a range of anthropogenic activities including: fisheries bycatch (Read et al. 2006), habitat destruction (Karczmarski et al. 2017), noise disturbance

(Erbe et al. 2018) and tourism (Christiansen et al. 2010). With their comparatively slow growth, late maturity, low fecundity and coastal distribution (Nelms et al. 2021; Temple et al. 2021), many cetacean species are therefore vulnerable to anthropogenic pressures within coastal habitats due to continuous urbanisation to support coastal communities. The welfare of coastal cetaceans at both individual and population levels can be threatened by the prevalence of anthropogenic sources such as noise disturbance from coastal construction (Piwetz et al. 2021), cetacean-watching tourism (Constantine et al. 2004), vessel strike (Schoeman et al. 2020) and fisheries bycatch (Brownell Jr. et al. 2019), which can cause injury (Kastelein et al. 2015; Martinez & Stockin 2013) and mortality (Reeves et al. 2013; Stone & Yoshinaga 2000), displacement (Leunissen et al. 2019) or reduction in fitness and reproductive success (Bejder et al. 2006; Lusseau et al. 2006). Odontocetes feed generally at high trophic levels and are vital for stability and productivity of marine ecosystem (Heithaus et al. 2008; Kiszka et al. 2015; Tavares et al. 2019), and if populations decline or are extirpated, this may destabilise or restructure the ecosystems through trophic cascade (Pinnegar et al. 2000).

Anthropogenic threats and their impacts on coastal cetaceans are global concerns but there are considerable lacks of monitoring and management in many regions, particularly in Southeast Asia where coastal activities and developments have rapidly expanded and caused deterioration to marine environments in recent decades (Beasley et al. 2013; Mustika et al. 2017). Detailed information and understanding of the ecology, distribution, population size, abundance, social structure and survival are crucial components for assessment of cetacean populations and to inform conservation and management strategies to ensure anthropogenic use of marine resources do not negatively impact cetacean populations (Huang et al. 2012; Jefferson et al. 2009; Sharpe & Berggren 2019).

Central-western Gulf of Thailand comprises of the coastal zones off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat. Don Sak and Khanom coastal waters represent a natural habitat for Indo-Pacific humpback dolphin (*Sousa chinensis*) (Jutapruet et al. 2017), a vulnerable shallow-and-coastal-resident odontocete species (Jefferson et al. 2017) that is widely distributed from Western Indian Ocean to Southeast Asia and Western Pacific Ocean (Jefferson & Karczmarski 2001), and is ubiquitously distributed along the Gulf of Thailand and the Andaman Sea (Adulyanukosol et al. 2014). Abundance surveys have estimated that the population size of Indo-Pacific humpback dolphins was 193 (95% CI: 167 – 249) in Don Sak water (Jutapruet et al. 2015) and 49 individuals (no reported 95% CI) in Khanom water (Jaroensutasinee et al. 2010). Relevant information regarding their demography and genetics have not been published to date. In Don Sak and Khanom, Indo-Pacific humpback dolphins and their habitats are affected by a number of anthropogenic activities: dolphin-watching and marine tourisms, fisheries catches, industrial transportation, ferry traffic and continuous expansion of coastal development projects to accommodate ferry ports, hotels/resorts/homestays and factories (Jutapruet et al. 2015). Nevertheless, there is very limited understanding of the potential effects imposed by anthropogenic activities on the biology and ecology of Indo-Pacific humpback dolphins in the central-western Gulf of Thailand.

Photo-identification (photo-ID) is a non-invasive data-collecting method using unique marks on the dorsal fin and adjacent areas on the body to identify cetacean individuals (Wursig & Wursig 1977). Photo-ID is a powerful technique and has been extensively used with capture-recapture analyses to investigate the biology and ecology of cetaceans around the world (Baird et al. 2009; Chen et al. 2018; Stensland et al. 2006; Tyne et al. 2014). It is feasible and logistically plausible in the central-western Gulf of Thailand to conduct the boat-based surveys and to collect photo-ID data of coastal Indo-Pacific humpback dolphins, which is a highly mobile species that do not undergo large-scale seasonal migrations (Jefferson & Karczmarski 2001). Presence of a number of anthropogenic activities and a rapid increase in boat-based dolphin-watching tourism off Don Sak and Khanom during the past decade pose potential threats to a vulnerable species like Indo-Pacific humpback dolphin (Jefferson et al. 2017). These developments have highlighted an urgent need for long-term, systematic and consistent research to provide the necessary information to assess the status of the species and the potential impacts from the anthropogenic activities to allow for proper management and development of any necessary mitigation strategies.

The aim of this study is to provide a new and updated estimate of the abundance for the Indo-Pacific humpback dolphins in the coastal areas off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand by collecting photo-ID data from boat-based surveys and to conduct Mark capture-recapture analyses. The new estimate of abundance is also imperative for putting the results presented in Chapters 3 “Spatio-Temporal Variations in Occurrence and Foraging Occurrence of Coastal Odontocetes off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Central-Western Gulf of Thailand, Based on Passive Acoustic Monitoring” and 4 “Effects of Boat-Based Dolphin-Watching Tourism on the Surface Behaviours and Vocalisations of Indo-Pacific Humpback Dolphins (*Sousa chinensis*) off Don Sak, Surat Thani, Thailand” in context of the species current status.

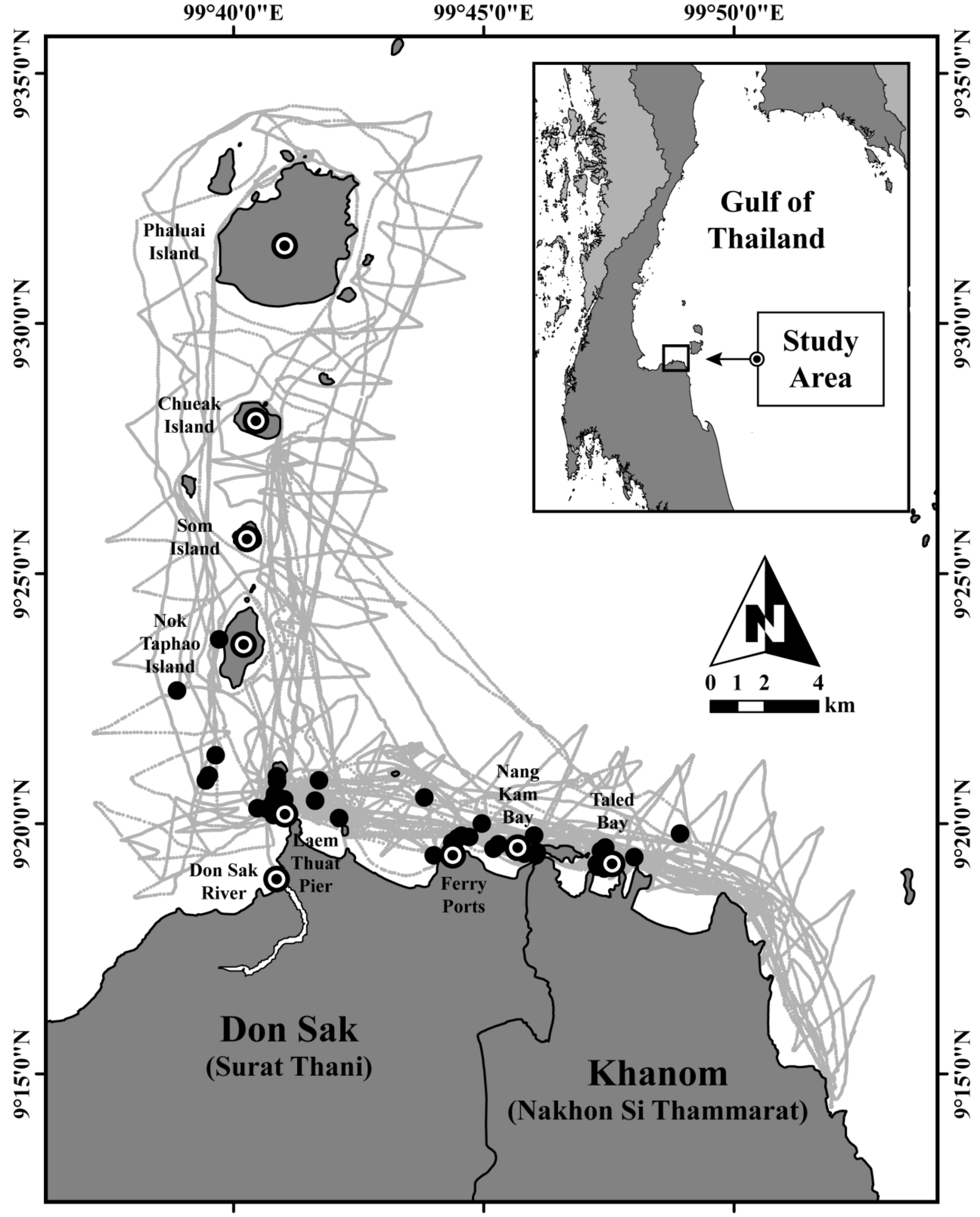


Figure 5.1 Boat-based survey routes from 33 survey days for photo-identification data of Indo-Pacific humpback dolphins (*Sousa chinensis*) off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand during May – July 2019. The survey tracks and sighting locations of Indo-Pacific humpback dolphin are presented by the grey track lines and black dots, respectively.

5.3 | Methods

5.3.1 Study area

The study was conducted off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand (Figure 5.1) where the water depth ranges between 1 – 10 m with a bottom sediment of mud flats, sand and seagrass. There are a number of anthropogenic activities conducted in the study area including small-scale fisheries, commercial fisheries, ferry traffic, shipping, pier construction, and boat-based dolphin-watching and other marine tourisms (personal observations).

5.3.2 Data collection

Boat-based surveys were conducted for 33 days during May – July 2019 and dedicated to finding and photographing groups of Indo-Pacific humpback dolphins in Don Sak and Khanom waters. The study used a long-tailed boat (length = 10 m and width = 2 m with outboard engine = 100 horsepower) which is commonly used by fishers in the study area. Survey routes were designed based on previous studies (Jutapruet et al. 2017) to cover all coastal areas occupied by the species. Before conducting the boat-based surveys, in-person meetings were held with subdistrict headmen and community (village) headmen in Don Sak and Khanom to present the study objectives.

All boat-based surveys in Don Sak and Khanom waters were conducted in Beaufort Sea State ≤ 2 during daylight hours (7:00 – 13:00 hrs). The boat-based surveys were paused when the Beaufort Sea State were > 2 or when there was heavy rain, which usually occurred in the afternoon after 13:00 hr due to seasonal effects of the south-westerly monsoon winds from the Indian Ocean during May – October. If such adverse conditions continued or escalated, the boat-based surveys were aborted.

Continuous sampling method (Mann 1999) was used for the boat-based survey to scan for dolphins. There were at least two observers on the survey boat, and every survey route taken each day was continuously tracked and recorded using a portable GPS navigator (Garmin eTrex 30x) (Figure 5.1). The survey boats travelled with slow speed (≤ 10 knots) to minimise potential disturbance to the animals. A dolphin encounter began with visual confirmation of the animal (e.g. dorsal fin, fluke or head) above the sea surface. When a dolphin group was encountered, the observer immediately recorded: time, location (GPS and area name), species, Beaufort Sea State, depth (measured by a portable depth sounder, Hondex PS-7).

Immediately after spotting dolphins, the survey boat slowed down and maintained the speed (< 4 knots) and distance to the dolphin group (50 – 150 m) following available cetacean-watching guidelines (Adulyanukosol et al. 2012b). Without the presence of dolphin-watching tourist boats, it was common that observed dolphin group remained in situ and allowed an extended observation time. However, if dolphins were travelling, the survey boat would match the speed and the follow the dolphin group parallel to the track line at appropriate distance (Adulyanukosol et al. 2012b). Dolphin group size and composition (calf and non-calf) were recorded after 5 – 10 minutes of observation. A group of dolphins was defined as an assembly of two or more non-calf dolphins where each individual was within 10 m from one another using a 10-m chain rule (Smolker et al. 1992).

Attempts were made to photograph both left and right sides of the dorsal fins of all individual dolphins present in the group. All images were taken using a Nikon D750 DSLR camera with an AF-S Nikkor 300mm f/4E PF ED VR telephoto lens and a Nikon D7700 DSLR camera with an AF-S VR Zoom-Nikkor 70-300mm f/4.5-5.6G IF-ED lens.

5.3.3 Data analysis

5.3.3.1 Photo-identification

All photographs were inspected, matched and processed using Adobe Lightroom Classic CC. Photo-identification (Urian et al. 2015; Wursig & Wursig 1977) started with the exclusion of low-quality images: photos with no dolphins, completely out of focus or capturing only tips of the dorsal fins. Photos showing only calves were also excluded from the analyses regardless of the image quality and individual distinctiveness since calves are not independent from their mothers and often lack features that allow individual identification. Further, photos showing two or more dolphin individuals (including pairs of mothers and calves) were duplicated for each individual (except for calves) and cropped to show only one individual's dorsal fin (with adjacent parts of body if available). Only high and moderate image qualities received an identification code and were used for creating the dolphin photo-ID catalogue and sightings history table.

A total of 1,534 photos were inspected. All encountered individual dolphins had highly distinctive dorsal fins and other markings allowing all animals to be individually identified: distinct shape or deformation of dorsal fin; distinct pigmentation pattern on dorsal fin and upper body; and distinct marks, nicks, ticks and scars. The sighting history data were then used for the capture-recapture analysis. Every four consecutive survey days were pooled to provide a single sampling occasion for capture-recapture analysis.

5.3.3.2 Abundance estimate

Capture-recapture analysis was conducted to estimate the abundance of the identified Indo-Pacific humpback dolphin using Program MARK (Version 9.x) (www.phidot.org/software/mark/). As all encountered dolphins had distinctive marks and were possible to individually identify, there was no need to calculate a proportion of marked/unmarked individuals in the population and to adjust the estimated abundance. Closed population estimation (closed-capture) models (Otis et al. 1978; White 2008) were selected as the most appropriate models for the analysis as the boat-based surveys were conducted during three months when demographic changes were unlikely. The assumptions of capture-recapture analysis with the validation and potential violation by the boat-based survey (Otis et al. 1978; Pollock et al. 1990) are presented in (Table 5.1).

Table 5.1 Assumptions of capture-recapture analyses with their validations and potential violations (Otis et al. 1978; Pollock et al. 1990), modified from Sharpe &Berggren (2019), by the boat-based surveys for Indo-Pacific humpback dolphins (*Sousa chinensis*) off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand during May – July 2019

Assumptions	**Validations and potential violations**
1. All individuals are marked.	All individuals of Indo-Pacific humpback dolphin were marked and could be individually identified. All marked individuals were used for capture-recapture analyses.
2. Marks are unique and not lost over time.	Given that all individuals were clearly distinctive and marked based on several features on the dorsal fin and adjacent areas: shape, colouration, marks, nicks, ticks and scars; they would still be identifiable even if they got new marks/injuries during the three-month sampling period.
3. Captures are independent.	Calves were excluded from the analyses as they are not independent from their mothers. Violation of this assumption would not bias the estimated population size but would cause an underestimation.
4. Capture probabilities are homogeneous for all individuals.	Boat-based survey routes were designed to maximise the encounter chance and to cover all areas distributed by Indo-Pacific humpback dolphins based on the previous surveys (Jutapruet et al. 2017). The sampling strategy might cause differences in capture probabilities if the animals used the surveyed habitat differently. However, closed capture-recapture models allow for the individual heterogeneity which account for potential violation of this assumption.
5. There are no behavioural responses/variations in capture-recapture probabilities.	There were no direct contacts with the animals during the entire study periods. Photographing dolphins represents a non-invasive data-collection method. The survey boat was a long tailed-boat (10-m long with 100-hp outboard engine) operated at slow speed (0 – 10 knots), carefully operated near the dolphin groups at low speed (< 4 knots) and distance (50 – 150 m) and travelling parallel to the animals (Adulyanukosol et al. 2012b) so that minimal disturbances/stress were caused. Some closed capture-recapture models allow for behavioural variations but were not considered in this study.
6. Population likely closed: no birth/death but a chance for temporal immigration/emigration.	Demographic closure is likely during a short study period of time (three months). However, temporary immigration and emigration may occur as cetaceans are highly mobile, which could bias the results.

Four closed capture-recapture models (Otis et al. 1978; White 2008) were used including: M_0 = model with constant capture-recapture probabilities; M_t = model with time-variation in capture-recapture probabilities; M_{h2} = model with individual heterogeneity in capture-recapture probabilities; and M_{th2} = model with time-variation and individual heterogeneity in capture-recapture probabilities. The model M_{th2} was the most parsimonious model based on the Akaike information criterion (AICc) (Akaike 1974; Burnham & Anderson 1998) (Table 5.2) and selected for the estimation of abundance.

Table 5.2 Akaike Information Criteria (AICc) ranking with corresponding abundance estimates (N-hat) and 95% confidence intervals of four closed capture-recapture models fitted to photo-identification data of Indo-Pacific humpback dolphins (*Sousa chinensis*) off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand during May – July 2019.

Model	**AICc**	**ΔAICc**	**AICc weight**	**Model likelihood**	**No. of parameter**	**Deviance**	**N-hat**	**95% CI**
M_{th2}	159.520	0	0.999	1	11	111.983	52	(49 – 62)
M_{h2}	173.813	14.293	0.001	0.001	4	140.880	53	(50 – 63)
M_t	201.795	42.275	0	0	9	158.486	49	(48 – 56)
M_0	211.412	51.892	0	0	2	182.553	50	(48 – 57)

5.3.4 Ethical approval

This study received ethical approval from the Newcastle University Ethics Committee (reference number: 12246/2018) and the Animal Welfare and Ethical Review Body (AWERB), Faculty of Medical Sciences, Newcastle University (Project ID number: ID 765).

5.4 | Results

5.4.1 Fieldwork summary

Indo-Pacific humpback dolphins were encountered on all 33 survey days with a total of 58 group sightings of Indo-Pacific humpback dolphins. Indo-Pacific humpback dolphin group size ranged from 1 to 11 dolphins with a median of 3 (95% CI: 2 – 5). A total of 48 non-calf Indo-Pacific humpback dolphins were photo-identified and photo-catalogued. Most dolphin sightings (50%) occurred around the areas of Laem Thuat Pier, while 35% occurred along the coastline from ferry ports to Nang Kam and Taled Bays, and the remaining 15% were sporadically encountered near islands and inshore areas. A cumulative discovery curve of the identified individual dolphins indicated that the population of Indo-Pacific humpback dolphins off Don Sak and Khanom was closed (Figure 5.2).

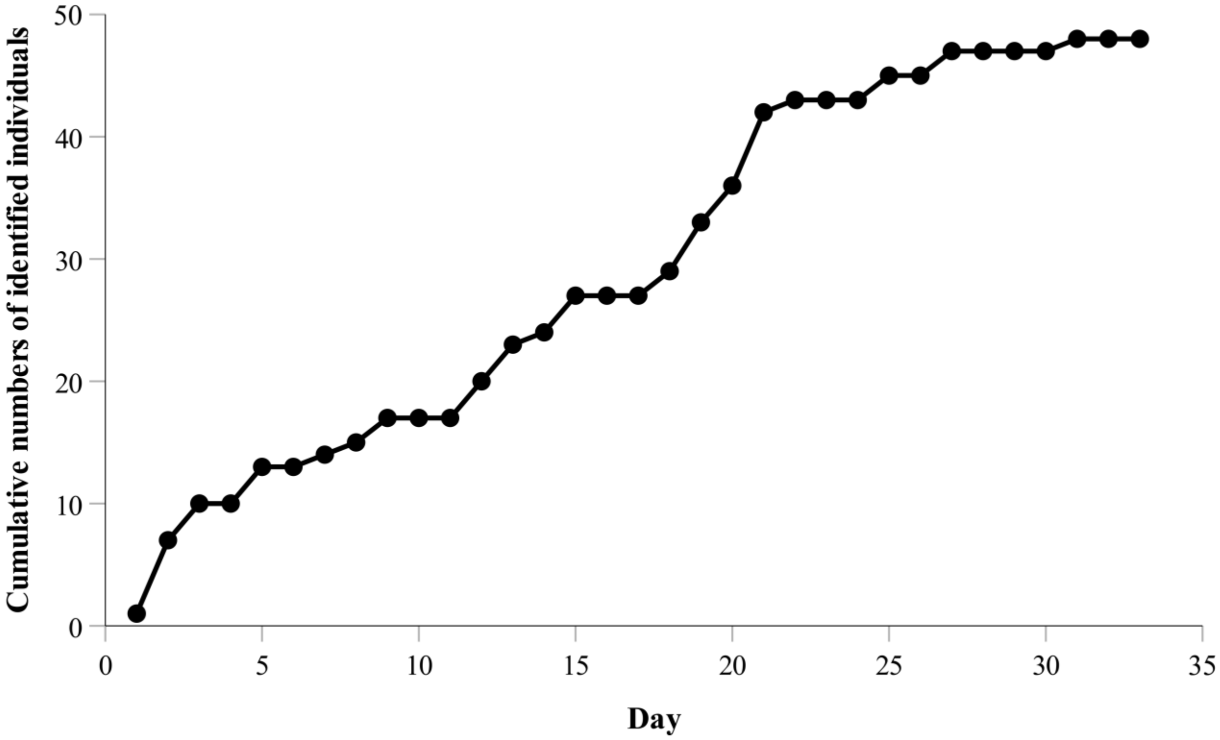


Figure 5.2 Cumulative discovery curve of photographically identified Indo-Pacific humpback dolphins (*Sousa chinensis*) off Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat, Thailand from 33 boat-based survey days during May – July 2019.

5.4.2 Abundance estimate

Based on the model M_{th2}, the estimated abundance for non-calf Indo-Pacific humpback dolphins off Don Sak and Khanom during May – July 2019 was 52 (95% CI: 49 – 62) (Table 5.2).

5.5 | Discussion

5.5.1 Abundance estimate

The estimated abundance of 52 (95% CI: 49 – 62) Indo-Pacific humpback dolphins off Don Sak and Khanom presented in this study represents a very small population size supported by the fact that most dolphins present in the study area during the time of the study were covered as indicated by the discovery curve. This therefore raises concerns if this is an isolated population as small cetacean populations are more vulnerable to extirpation due to low genetic variability and low resilience to environmental stochasticity (Caughley & Gunn 1997; Vachon et al. 2018). Populations with less than 100 animals face high extinction probabilities as indicated in studies of Indian Ocean humpback dolphins (*Sousa plumbea*) (Sharpe & Berggren 2019) and common bottlenose dolphins (*Tursiops truncatus*) (Thompson et al. 2000).

The 2019 population/abundance estimates of Indo-Pacific humpback dolphin off Don Sak and Khanom is similar to the population size/abundance for the same species in Cleveland Bay, Australia [46 (95% CI: 21 – 59)] (Parra et al. 2006) and smaller than some areas including the Xiamen Bay, China [70 (95% CI: 63–88)] (Chen et al. 2018); the eastern Taiwan Strait [99 (95% CI: 37 – 266)] (Wang et al. 2007); and Hong Kong waters [368 (95% CI: 320 – 422)] (Chan & Karczmarski 2017). The population/abundance estimate presented here was very similar to an estimate from 2010 of 49 (no reported 95% CI) (Jaroensutasinee et al. 2010) but lower than a 2015 estimate of 193 (95% CI 167 – 249) (Jutapruet et al. 2015). The three studies covered similar, but not identical areas, had different temporal sampling periods, although the 2010 and 2015 studies overlapped. Given that 15 identified dolphins were matched between this and the previous study from 2015 (Jutapruet et al. 2015), this indicated that they likely covered the same population. Indo-Pacific humpback dolphins are generally found in small resident populations (Jefferson et al. 2017) so it is unclear what may have caused the apparent fluctuation in numbers in 2010, 2015 and 2019, but temporal immigration/emigration may offer one possible explanation. The different analysis methods applied in the three studies may also have affected the estimated abundance and a re-analysis using all three studies data would possibly help clarify the difference in abundance among the years. This was not possible for this study as the data from the 2010 study was not accessible.

It is important to emphasise that this study did not include calves in the analyses as previous studies in the same areas did (Jaroensutasinee et al. 2010; Jutapruet et al. 2015). Closed-population models were used to estimate the abundance because it fitted all the assumptions of capture-recapture analysis (Otis et al. 1978; Pollock et al. 1990). While Jaroensutasinee et al. (2010) and Jutapruet et al. (2015) used open-population models for the estimation and the population of Indo-Pacific humpback dolphins has fluctuated for the past 4 – 9 years, closed-population models were selected for this study mainly due to a short study period of time (three months: May – July 2019), where demographical changes were unlikely. Most importantly, most individuals in the population were sighted and included in the analysis indicated by the cumulative discovery curve reaching plateau phase. Therefore, the new abundance estimates in this study is not directly comparable to the estimates in 2010 and 2015 (Jaroensutasinee et al. 2010; Jutapruet et al. 2015).

5.5.2 Group size

Indo-Pacific humpback dolphins commonly have small group sizes (< 10) (Jefferson & Karczmarski 2001). The median/range of group size of Indo-Pacific humpback dolphins off Don Sak and Khanom presented in this study were similar to those reported in 2010 (range: 2 – 20) (Jaroensutasinee et al. 2010) and 2015 (range: 1 – 18) (Jutapruet et al. 2015); and similar to other populations in Hong Kong (range: 1 – 13) (Parsons 1998) and Australia (range: 1 – 12) (Beasley et al. 2015b), but less than those reported in Taiwan (median: 4, range: 1 – 31) (Dares et al. 2014), Papua New Guinea (range: up to 32) (Beasley et al. 2015a) and China (range: 1 – 30) (Li et al. 2019). Group size can reflect competition level for food resources as smaller group size would reduce intraspecific competition when food resources are limited (Heithaus & Dill 2002; Parra et al. 2011). The relatively small group size presented here may suggest this but requires further robust investigation.

5.5.3 Distribution

Indo-Pacific humpback dolphins off Don Sak and Khanom had a highly concentrated distribution close inshore and in shallow areas. The relatively high occurrence of Indo-Pacific humpback dolphins at Laem Thuat Pier (50% of sightings) was likely influenced by the Don Sak River. High turbid delta accumulated with organic and inorganic matters provides nutrient enrichment (Torregroza-Espinosa et al. 2020; Wang et al. 2019a; Zhou et al. 2008) driving productivity and attracting the prey and predators including fish (e.g. Family Mugilidae), molluscs and crustaceans (Barros et al. 2004; Parra & Jedensjö 2014), which are the main prey of Indo-Pacific humpback dolphins in the central-western Gulf of Thailand (Jutapruet et al. 2015). This is also supported by the results from Chapters 3 and 4. Further, other Indo-Pacific humpback dolphin populations in the eastern Taiwan Strait (Wang et al. 2007), Hong Kong waters (Jefferson 2000), the Pearl River Estuary, China (Huang et al. 2012; Hung & Jefferson

2004) and the Cleveland Bay, Australia (Parra et al. 2006) have also reported that Indo-Pacific humpback dolphins to inhabit coastal areas near river mouths and estuaries.

The complete home range of Indo-Pacific humpback dolphins in the central-western Gulf of Thailand is yet to be discovered. However, the distribution range of Indo-Pacific humpback dolphins found in this study was smaller and more contracted compared to the results from 2015 covering a similar survey area but also encountered dolphins off the northern islands including Som, Chueak and Phaluai Islands (Jutapruet et al. 2015). Absence of dolphin sightings off the northern islands during May – July may represent a seasonal shift in distribution pattern and relative abundance in the area, which have been observed in other distribution areas for the genus *Sousa* (Chen et al. 2010; Jefferson & Karczmarski 2001; Karczmarski et al. 1999).

5.5.4 Threats

Indo-Pacific humpback dolphins have been exposed to a number of threats in Don Sak-Khanon waters including fisheries bycatch (Chapter 2), coastal construction (personal observation), noise disturbance (personal observation), habitat degradation (personal observation), dolphin-watching tourism (Chapter 4) and potential vessel strike (Chapter 4). These anthropogenic activities will have negative effects on individuals leading to displacement or decreased population (Brownell Jr. et al. 2019; Piwetz et al. 2021; Schoeman et al. 2020).

Don Sak and Khanom coastal waters are occupied by small-scale and commercial fisheries, and these were likely responsible for some of the injuries observed on dolphins photographed during the study. Fisheries bycatch represents one of the greatest anthropogenic threats to cetaceans (Brownell Jr. et al. 2019; Reeves et al. 2013), particularly in coastal areas (Temple et al. 2021) including the genus *Sousa* with small populations and generally low population growth (Jefferson & Karczmarski 2001). Increased mortality due to fisheries interactions (e.g. gillnet entanglement) can drive small cetacean populations close to extinction (Brownell Jr. et al. 2019; Taylor et al. 2017).

Ongoing coastal construction using pile driver in the study area during the study would likely have been a threat to the dolphins (personal observation). Such construction activities can create noise disturbance that may cause displacement (Dähne et al. 2013; Leunissen et al. 2019), alteration in foraging and resting behaviours (Piwetz et al. 2021), increase of stress (Erbe et al. 2018) and damage in auditory system (Kastelein et al. 2015; Leunissen & Dawson 2018). Moreover, habitat degradations by human and climate drivers (Canadas & Vazquez 2017; Jefferson 2018; Piwetz et al. 2021) can lead to decreased food/prey availability and increased competition for Indo-Pacific humpback dolphins driving them to migrate to distant areas for new food resources (Karczmarski et al. 2000).

Don Sak and Khanom are well-known hotspots for dolphin-watching and marine tourisms which have become an alternative source of income and a part of livelihood for the coastal communities (Jutapruet et al. 2015; Mustika et al. 2017), attracting 10,000 tourists and dolphin-watching enthusiasts yearly (Mustika et al. 2017). Chapter 4 showed that the current intensity of dolphin-watching tourism in the study area significantly affected the surface and acoustic behaviours of Indo-Pacific humpback dolphins off Don Sak. Repetitive behavioural disruption can lead to increased stress (Bechdel et al. 2009; Fair & Becker 2000) and decreased reproductive success (Christiansen & Lusseau 2015; New et al. 2015), which will ultimately lead to the decline of populations (Bejder et al. 2006; Lusseau et al. 2006). Further, the prevalence of vessel traffic off Don Sak and Khanom, including approximately 140 dolphin-watching boats, potentially poses injury/mortality risks of vessel strike and propeller cut (Schoeman et al. 2020; Stone & Yoshinaga 2000). This is likely to be caused by tourist speed boats as they were regularly observed violating the dolphin-watching guidelines (Adulyanukosol et al. 2012b) during dolphin-watching sessions.

5.5.5 Recommendations for future research and management

Large-temporal scale survey effort could not be achieved in this study because the boat-based surveys using a small long-tailed boat were limited during monsoon season in 2019 and were prohibited in 2020 due to the COVID-19 pandemic. Future systematic research with greater effort covering broader spatio-temporal scales to create long-term, consistent and comparable data for all cetacean species in the study area is highly recommended. Although the survival rate and prediction for potential extirpation cannot be estimated due to limited data, the small population size/abundance of Indo-Pacific humpback dolphin presented here suggests that species is likely at risk in the study area. Future research should aim to set-up a long-term and consistent assessment protocol for robust yearly estimation of population parameters including, abundance, distribution, residency, genetic structure and demography.

Extended human pressures due to prevalent anthropogenic activities (e.g. fisheries, construction and tourism) in the coastal areas should be monitored and mitigation strategies are recommended to reduce potential impact. The number, speed and operation of dolphin-watching tourist boats and other watercrafts entering the areas should be regulated to reduce pressures on the dolphins. Watercrafts for recreational purposes such as jet skis and speed boats should be prohibited or strictly regulated at Laem Thaut Pier to minimise disturbance/harassment and a risk of vessel strike. To achieve recommended conservation and management actions, cooperation from local communities, stakeholder organisations and local authorities is needed.

CHAPTER 6

Thesis Conclusion

6.1 | Small-scale fisheries threats to marine megafauna in Thailand

The current understanding of the anthropogenic impacts on marine megafauna (marine mammals, sea turtles and elasmobranchs) in Thailand is very limited. Small-scale fisheries (SSF) are numerous and distributed across all coastal areas of the Gulf of Thailand and the Andaman Sea. The official Thai fishing vessel statistics from the Department of Fisheries indicate that there were 14,946 registered SSF vessels operating off Thailand in 2014 (DOF 2016). However, this is a substantial underestimate because the reported vessel numbers in the Thai official statistics do not match what has been reported to the Food and Agriculture Organisation (FAO). A previous estimation gave an estimate of 56,378 SSF vessels in Thailand for the year 2004 (Lymer et al. 2008) and Chapter 1 of this thesis provides a mean estimate of 56,001 (95% CI: 50,360 – 61,642) SSF vessels in Thailand for the period 2005 – 2018 based on collated vessel data statistics available from FAO (FAO 2020a). The most likely explanation between the difference between the DOF and the FAO statistics is that the DOF only includes vessels for which fishing gear type is available and excludes the category "Other fishing vessels" which are reported to the FAO. Given that the official Thai fishing vessel statistics from DOF were used in Chapter 2 for the assessment of marine megafauna catch in Thai SFF, the estimates presented in the chapter represent absolute minimum numbers as they have not been adjusted based on the mismatch been the DOF and the FAO statistics for the number of vessels.

The issues relating to the fisheries statistics is further highlighted by results of the questionnaire survey with the Thai SSF fishers in Chapter 2. The results showed that the fishers used 21 different gear types while only 11 gear types were reported in the Thai official fishing vessel statistics (DOF 2016). In contrast, the number of vessels by métier (gear types) reported in the FAO official fisheries statistics were limited to four: gillnets, longlines, other lines and traps (FAO 2020a). There is consequently a great need for improved data collection and reporting to provide the necessary fishery statistics to allow comprehensive assessment of the SFF catch and impact on vulnerable megafauna. Nevertheless, the level of SSF in Thai coastal waters will likely have substantial negative impacts on marine megafauna populations and the marine ecosystems (Brownell Jr. et al. 2019; Dulvy et al. 2021; Lewison et al. 2004; Lewison et al. 2014; Temple et al. 2021).

The research presented in Chapter 2 represents the first independent investigation of megafauna catch in Thai SSF. Crab gillnets and shrimp trammel nets were overall the dominant gears contributing the majority of the estimated catches across all megafauna groups driven by high catch per unit effort (CPUE) and/or high effort. A comprehensive assessment of the vessels using crab gillnets and shrimp trammel nets should be therefore conducted using a rigorous framework (see e.g. Wade et al. 2021) and immediate mitigation should be initiated to reduce catches of already threatened megafauna to avoid extirpation. Finally, to reiterate given that estimates provided in Chapter 2 are considered as minimum estimates, the situation is likely worse than indicated and therefore requires immediate attention.

6.2 | Other anthropogenic threats to coastal odontocetes in the central-western Gulf of Thailand

In addition to the threat from fisheries catch, there are a number of other anthropogenic activities that pose threat to marine megafauna and cetaceans in particular in Thai coastal waters including cetacean-watching tourism (Christiansen & Lusseau 2014; Mustika et al. 2017), vessel strikes (Schoeman et al. 2020; Stone & Yoshinaga 2000), coastal construction (Piwetz et al. 2021) and noise disturbances (Bechdel et al. 2009). As presented in Chapter 4, the changes in short-term behaviours caused by the current intensity of dolphin-watching tourism of Indo-Pacific humpback dolphins (*Sousa chinensis*) off Don Sak are a cause for concern and if continued may lead to long-term effects on individual fitness (survival and reproduction) (Christiansen & Lusseau 2015; New et al. 2015), which ultimately could lead to population effects/decline (Bejder et al. 2006; Lusseau et al. 2006). To date, research on cetaceans in Thailand have been limited to a few species in some areas (Hines et al. 2015; Jaroensutasinee et al. 2010; Jutapruet et al. 2015; Jutapruet et al. 2017; Niu et al. 2021; Niu et al. 2019; Svarachorn et al. 2016), and the effects of anthropogenic threats to cetaceans such as dolphin-watching tourism have not been comprehensively investigated in Thailand (Mustika et al. 2017).

The research in Chapter 3 represents the first study in Thailand using Passive Acoustic Monitoring (PAM) to investigate the occurrence and foraging occurrence of odontocetes: Indo-Pacific humpback dolphin, Irrawaddy dolphin (*Orcaella brevirostris*) and Indo-Pacific finless porpoise (*Neophocaena phocaenoides*), and potential environmental drivers for their occurrence and foraging occurrence in the central-western Gulf of Thailand. The results in Chapter 3 showed that the spatio-temporally occurrence and foraging occurrence of the odontocetes were driven by both location and environmental factors: diel cycle, month, tide phase and moon phase. The study found that Laem Thuat Pier had the highest occurrence and foraging occurrence across the three study sites, possibly influenced by the nutrient-rich water entering the area from the Don Sak River providing high productivity and availability of dolphin prey, indicating that this area may be of particular importance for odontocetes in the central-western Gulf of Thailand.

The research presented in Chapter 4 represents the first study in Thailand using simultaneous shore-based observations and PAM data collection to investigate the potential effects of boat-based dolphin-watching tourism on surface behaviour and vocalisation of Indo-Pacific humpback dolphins. Chapter 4 showed that the dolphin-watching tourism activities off Don Sak, Surat Thani, Thailand had significant short-term effects on the surface and acoustic behaviours of Indo-Pacific humpback dolphins. Dolphin-watching tourism in Don Sak and Khanom waters was aggressive and erratic: tourist boats regularly approached and followed the dolphins at close range (1 – 10 m), and were often observed travelling and cutting through the dolphin groups or near the groups (1 – 5 m) at full speed (personal observation). The current level and implementation of the dolphin-watching tourism off Don Sak raise serious concerns and if continued without proper mitigation and management may lead to long-term negative effects on individual dolphin fitness (survival and reproduction) (Christiansen & Lusseau 2015; New et al. 2015), which may ultimately may lead to decline of Indo-Pacific humpback dolphins off Don Sak and Khanom (Bejder et al. 2006; Lusseau et al. 2006).

The thesis study area in the central-western Gulf of Thailand (Don Sak, Surat Thani and Khanom, Nakhon Si Thammarat) features a number of additional anthropogenic threats to odontocetes. Besides SSF fisheries and dolphin-watching tourism, vessel strike/collision, coastal construction, fisheries and noise disturbance are other important anthropogenic factors threatening the welfare and survival of the odontocetes present. Given the relatively small abundance estimated for the Indo-Pacific humpback dolphins (Chapter 5) and the ongoing anthropogenic threats, conservation and management actions are recommended to prevent potential extirpation of the species in the study area.

6.3 | Recommendations for future conservations and managements: marine megafauna catch in Thai small-scale fisheries

6.3.1 Future works on catch assessments

The results of the research in this thesis have demonstrated that marine megafauna in Thai coastal waters are threatened by anthropogenic activities. Specifically, conservation and management mitigation actions are needed to reduce catch of vulnerable marine megafauna in SFF fisheries and to regulate how boat-based dolphin tourism is conducted to prevent species extirpation and extinction in Thai coastal waters.

There is further need for improved fisheries statistics to include effort and catch data for all SSF gears to allow comprehensive assessment. Categorisation of SSF gear, fishing effort, species caught, catch numbers, catch composition, catch per unit effort (CPUE) and annual estimated catch are fundamental and essential components for catch assessment, and should therefore be recorded and reported using consistent methods and effort metrics.

Questionnaire-based interviews have been demonstrated in this thesis and by other studies (Alfaro-Shigueto et al. 2018; Kiszka 2012; Moore et al. 2010; Mustika et al. 2021) as a quick, feasible and an efficient survey method with capability to collect substantial data in areas/regions where catch information is unknown or limited. However, future research following this study should consider recording all marine megafauna catch at landings sites

(Temple et al. 2019) and following on this an onboard vessel sampling schemes should be initiated with independent observers and/or using remote electronic video monitoring (Bartholomew et al. 2018; WWF 2017). It is recommended that Thai government agencies, including the Department of Fisheries (DOF) and Department of Marine Coastal Resources (DMCR), should create a centralised catch and fishing effort database that is published and that data are made accessible to the public. Such data will provide better understanding of the catch situation of marine megafauna in Thailand and will inform necessary research conservation and management strategies to ensure future viable megafauna populations (Crowder et al. 2008; Di Tullio et al. 2015). Failure to initiate conservation measures may lead to severe decline, extirpation or extinction of populations and species which may result in destabilisation or restructuring of marine ecosystem through trophic cascade (Pan et al. 2016; Pinnegar et al. 2000).

6.3.2 Recommendations for mitigation policies

To reduce the annual catch of marine megafauna in SSF, the use of crab gillnets and shrimp trammel nets should be suspended or banned during a closed season (March – May) in the Gulf of Thailand and the Andaman Sea to allow megafauna to repopulate. Violation of closed-season policy should result in prosecution. Traps and pots are recommended as possible alternative fishing gears for gillnets/nets because of their relatively lower CPUE and to catch sea turtles or marine mammals. In fact, a limit to the number of gillnets should be allowed to use for each vessel per one-day fishing trip to reduce potential excessive fishing. Light-Emitting Diode (LED) lights on gillnets (Lucas & Berggren 2022), Acoustic Deterrent Devices (ADDs) or “Pingers” (Dawson et al. 2013; Gazo et al. 2008), Bycatch Reduction Devices (BRDs) and Turtle Excluder Devices (TEDs) (Willems et al. 2016) can reduce megafauna catch and should be considered as part of future regulations. This requires collaboration by manufacturers and policies mandated by government. Despite of strict enforcement, fishers are key collaborators in catch reduction efforts as mitigation success is substantially depended on their willingness, collaboration and compliance (Alava et al. 2019).

6.4 | Recommendations for future conservations and managements: boat-based dolphin-watching tourism in the central-western Gulf of Thailand

6.4.1 Current status

Despite odontocetes being legally protected (Ezekiel 2018; GG 1992; GG 2014; GG 2019) and are positively viewed by the Don Sak and Khanom communities, anthropogenic threats including dolphin-watching tourism, marine tourism, vessel strike, propeller cut, bycatch in small-scale & commercial fisheries and coastal development projects; are neither systematically assessed nor monitored in the central-western Gulf of Thailand. Furthermore, the current jurisdictions and protection boundaries of Mu Ko Ang Thong National Marine Park (DNP 2021b) and Hat Khanom – Mu Ko Thale Tai National Marine Park (DNP 2021a) do not include the areas off Laem Thuat Pier and adjacent waters of Don Sak.

6.4.2 Recommendations for mitigation policies

Laem Thuat Pier, Don Sak, Surat Thani, Thailand were suggested by Jutapruet et al. (2017) as core habitats for Indo-Pacific humpback dolphins and Irrawaddy dolphins and possibly also for Indo-Pacific finless porpoises in the central-western Gulf of Thailand. This was also supported from the research conducted as part of this thesis which had 100% visual and acoustic odontocete encounter rates per survey day (Chapters 3, 4 and 5, personal observation). Laem Thuat Pier could therefore be promoted as a hotspot for shore-based dolphin-watching to mitigate boat-based-tourism pressures on the animals without reducing the economic benefits to the local communities. Tourists come to the pier every day to use the ferry services or to see dolphins, and this creates opportunities for the local economy. As shown in Chapter 4 of this thesis dolphins can be clearly observed from the pier, coin-operated binoculars and guided tours explaining about the dolphins can be ways to support dolphin-watching activities without disturbing the animals. Further, public education and promoting local awareness/appreciation of marine resources should also be used to implement conservation actions (García-Cegarra & Pacheco 2017; Orams 1997).

Based on the current situation, first, Don Sak local government should prioritise its strategies on prohibiting and regulating any recreational watercrafts (e.g. jet skis and speed boats) from entering the pier area, as their erratic and aggressive activities could cause vessel strike/collision to dolphins. Prosecution should be made when regulations are violated. Second, all tourism activities should be regulated and assessed. Restriction should include: the number of tourist boats entering the areas; boat speed; distance between boat and dolphin group (< 30 m); and inappropriate behaviours (e.g. physical contact, offering food and swim with dolphin) (Adulyanukosol et al. 2012b; Berggren et al. 2007; Chen 2011; Wu et al. 2020). Third, only tour operators and boat captains, who are certified and licensed from a dolphin-watching teaching programme, should be allowed to conduct any dolphin-watching activities. Fourth, it is recommended to assign authorised officers at Laem Thuat Pier to monitor and record all dolphin-watching boat activities daily; for example, number of boats interacting with a dolphin group, boat speed, boat-to-dolphin distance and how dolphin respond to the boat. When regulations are violated or any misbehaviours occur, these officers can press charges on any tour operators or tourists. Fifth, to introduce and help tourists understand how to behave on boats, information boards and brochures should be provided. Sixth and most importantly, the duration of 19 minutes (Chapter 4) should be enacted in the Thai dolphin-watching regulation as maximum interaction time between tourist boats and dolphins to minimise potential negative impacts on the animals (Chen 2011; Guerra & Dawson 2016; Wu et al. 2020). Seventh, a closed-season for tourism (Berggren et al. 2007) should be mandated by local government of Don Sak and Khanom from October – January (monsoon season) to allow dolphins an undisturbed period to recover.

As the core habitats for coastal odontocetes in the central-western Gulf of Thailand, Laem Thuat Pier and adjacent waters of Don Sak are yet included in the national marine park areas (DNP 2021a; DNP 2021b), this allows erratic or inconsiderate watercrafts to increase chance of odontocete mortality. It is therefore proposed that the Department of National Park, Wildlife and Plant Conservation (DNP) and associated government agencies in the central-western Gulf of Thailand consider extending the jurisdiction and protection boundaries to cover Laem Thuat Pier.

Finally, designation of marine protected areas with enforced regulations regarding anthropogenic activities including fisheries and tourism should be considered as one possible solution to mitigate the anthropogenic impacts on odontocetes and other marine megafauna in Thai coastal waters (Gormley et al. 2012; Jefferson et al. 2009; Passadore et al. 2018). Failure to implemented necessary conservation and management actions will ultimately lead to extirpation or extinction of many coastal marine megafauna species.

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APPENDIX

Appendix 1

Questionnaire interview form used in face-to-face interviews with the fishers from 32 small-scale fishing communities in 17 provinces along the Gulf of Thailand and the Andaman Sea, Thailand during September – December 2017. Adapted from the Rapid Bycatch Assessment (RBA) (Alfaro-Shigueto et al. 2018; Moore et al. 2010; Temple et al. 2020).

RBA Questionnaire Interviews

September - December | 2017

Survey Ref. No.	**Date**	**Interviewer**
Location/Village (GPS)		**Occupation**

Introduction by Interviewer

Hello, my name is Thevarit Svarachorn (New). I am a PhD student at the School of Natural and Environmental Sciences, Newcastle University in the United Kingdom, who wants to contribute to future sustainable local fisheries in Thailand for you and your children. To facilitate this a comprehensive review is needed of the fisheries, I believe the best way to do this is to gather the information from those who are directly involved in the fisheries.

The purpose of this survey is to gather information about fishing activities in the Thai small-scale fisheries. The survey includes questions about the gears you use, when and where you are fishing. However, I want to assure you that any information you provide is confidential and cannot be traced back to you. I hope you are willing to share your knowledge which would be a tremendous contribution to this work. I greatly appreciate your willingness and time to participate in this questionnaire survey.

Survey Ref. No. (Province/Village/Interview No.)

No.	Province	Code	No.	Province	Code
1	Trat	*Trat*	11	Surat Thani	*Su*
2	Chantaburi	*Chan*	12	Nakhon Si Thammarat	*Nak*
3	Rayong	*Ray*	13	Songkhla	*Song*
4	Chonburi	*Chon*	14	Satun	*Sat*
5	Samut Prakhan	*SaPra*	15	Trang	*Tra*
6	Samut Sakhon	*SaSa*	16	Krabi	*Kra*
7	Samut Songkhram	*SaSo*	17	Phuket	*Phu*
8	Phetchaburi	*Phe*	18	Phang Nga	*Pha*
9	Prachuap Khirikhan	*Pra*	19	Ranong	*Ra*
10	Chumphon	*Chum*	**e.g.**	Trat / 01 / 001	

Fishing Gear Questions

1. What **types** of fishing gears do you use and which one is your **main gear** in the last year (12 months)?
[Use illustrations, circle/fill in the gear type(s), mark an "X" in front of one as the main gear]

2. Which **months** do you usually use these gears, and how many **days per month** do you go fishing with them?
[*Circle month(s) in which gear is used below]*

3. On an average trip, **how many** of these fishing gears do you take with you, and **where** do you use them?

Gear types	Gear size	Months used	Usage (D/M)	No. of gears	Location used
Crab gillnets		J F M A M J J A S O N D			
Shrimp trammel nets		J F M A M J J A S O N D			
Fish bottom gillnets		J F M A M J J A S O N D			
Fish drift gillnets		J F M A M J J A S O N D			
Mackerel gillnets		J F M A M J J A S O N D			
Handlines		J F M A M J J A S O N D			
Fishing rods and reels		J F M A M J J A S O N D			
Longlines		J F M A M J J A S O N D			
Traps		J F M A M J J A S O N D			
Push nets		J F M A M J J A S O N D			
Pound nets		J F M A M J J A S O N D			
Lift nets		J F M A M J J A S O N D			
Ray gillnets		J F M A M J J A S O N D			
Squid Jigs		J F M A M J J A S O N D			
Squid falling nets		J F M A M J J A S O N D			
		J F M A M J J A S O N D			
		J F M A M J J A S O N D			
		J F M A M J J A S O N D			
		J F M A M J J A S O N D			
		J F M A M J J A S O N D			

4. With your **main fishing gear**, what are the **top-three target species**? *[1-3 answers allowed]*

1) ________________________ 2) ________________________ 3) ________________________

Ray Questions

1. Have you ever caught **rays** using your fishing gears in the last year (12 months)?
[Show illustrations, circle one, if answer is "No" or "Don't Know" skip to next section]

Yes No Don't Know

2. For each of the following sea turtle type in the table; within the last year (12months):
    2.1 **How many** rays did you catch in total with **all of your gears** and only **main gear**?
    2.2 What **months** and **where** did you catch them?
[Circle "All rays" first to record the overall catch no. > then ask the fishermen in further (use the illustrations) if they can identify the species / if they can't identify, skip to no.3]

Species	**Months caught**	**Caught no.**	**Gear caught**	**Location caught**
All Rays	J F M A M J J A S O N D			
Sting/whip	J F M A M J J A S O N D			
Small sting/whip	J F M A M J J A S O N D			
Eagle	J F M A M J J A S O N D			
Butterfly	J F M A M J J A S O N D			
Devil	J F M A M J J A S O N D			
Guitar	J F M A M J J A S O N D			
Wedge	J F M A M J J A S O N D			
Numb	J F M A M J J A S O N D			
Saw	J F M A M J J A S O N D			
	J F M A M J J A S O N D			
	J F M A M J J A S O N D			

3. What did you **do** with the rays you caught? *[Open question / ≥ 1 answers allowed]*

Release alive Discard dead Eat Sell part Sell whole

Other: ____________________

4. Do rays **damage** your fishing gear? Yes No Don't Know

5. How do rays **affect** your fishing? ____

6. How do you describe ray's **population trend** in this year compared to the previous year?

Increasing Same Decreasing Don't Know

Shark Questions

1. Have you ever caught **sharks** using your fishing gears in the last year (12 months)?
[Show illustrations, circle one, if answer is "No" or "Don't Know" skip to next section]

Yes No Don't Know

2. For each of the following shark type in the table; within the last year (12months):

2.1 **How many** sharks did you catch in total with **all of your gears** and only **main gear**?

2.2 What **months** and **where** did you catch them?

[Circle "All sharks" first to record the overall catch no. > then ask the fishermen in further (use the illustrations) if they can identify the species / if they can't identify, skip to no.3]

Species	**Months caught**	**Caught no.**	**Gear caught**	**Location caught**
All Sharks	J F M A M J J A S O N D			
Reef	J F M A M J J A S O N D			
Bamboo	J F M A M J J A S O N D			
Gummy	J F M A M J J A S O N D			
Nurse	J F M A M J J A S O N D			
Thresher	J F M A M J J A S O N D			
Zebra	J F M A M J J A S O N D			
Tiger	J F M A M J J A S O N D			
Sand tiger	J F M A M J J A S O N D			
Hammerhead	J F M A M J J A S O N D			
Whale	J F M A M J J A S O N D			
	J F M A M J J A S O N D			

3. What did you **do** with the sharks you caught? *[Open question / ≥ 1 answers allowed]*

Release alive Discard dead Eat Sell fins Sell whole

Sell part (meat) Other: ____________________

4. Do sharks **damage** your fishing gear? Yes No Don't Know

5. How do sharks **affect** your fishing? ____

6. How do you describe shark's **population trend** in this year compared to the previous year?

Increasing Same Decreasing Don't Know

Sea Turtle Questions

1. Have you ever caught **sea turtles** using your fishing gears in the last year (12 months)?
[Show illustrations, circle one, if answer is "No" or "Don't Know" skip to next section]

Yes No Don't Know

2. For each of the following sea turtle type in the table; within the last year (12months):
   2.1 **How many** sea turtles did you catch in total with **all of your gears** and only **main gear**?
   2.2 What **months** and **where** did you catch them?

[Circle "All sea turtles" first to record the overall catch no. > then ask the fishermen in further (use the illustrations) if they can identify the species / if they can't identify, skip to no.3]

Species	Months caught	Caught no.	Gear caught	Location caught
All Sea turtles	J F M A M J J A S O N D			
Green	J F M A M J J A S O N D			
Hawksbill	J F M A M J J A S O N D			
Olive Ridley	J F M A M J J A S O N D			
Loggerhead	J F M A M J J A S O N D			
Leatherback	J F M A M J J A S O N D			

3. What did you **do** with the sea turtles you caught? *[Open question / ≥ 1 answers allowed]*

Release alive Discard dead Eat (meat) Eat (egg) Sell shell

Sell whole Sell part (meat) Sell egg Other: ___________________

4. Do sea turtles **damage** your fishing gear? Yes No Don't Know

5. How do sea turtles **affect** your fishing? ____

6. How do you describe sea turtle's **population trend** in this year compared to the previous year?

Increasing Same Decreasing Don't Know

7. Do you know of any **nesting areas** (egg-laying areas) for sea turtles? Yes No

If yes, describe: ____

Dolphin Questions

1. Have you ever caught **dolphins** using your fishing gears in the last year (12 months)?
[Show illustrations, circle one, if answer is "No" or "Don't Know" skip to next section]

Yes No Don't Know

2. For each of the following dolphin type in the table; within the last year (12months):

2.1 **How many** dolphins did you catch in total with **all of your gears** and only **main gear**?

2.2 What **months** and **where** did you catch them?

[Circle "All dolphins" first to record the overall catch no. > then ask the fishermen in further (use the illustrations) if they can identify the species / if they can't identify, skip to no.3]

Species	Months caught	Caught no.	Gear caught	Location caught
All dolphins	J F M A M J J A S O N D			
Irrawaddy	J F M A M J J A S O N D			
Humpback	J F M A M J J A S O N D			
Bottlenose	J F M A M J J A S O N D			
Finless	J F M A M J J A S O N D			
Long-beaked	J F M A M J J A S O N D			
Risso	J F M A M J J A S O N D			
	J F M A M J J A S O N D			
	J F M A M J J A S O N D			
	J F M A M J J A S O N D			

3. What did you **do** with the dolphins you caught? *[Open question / ≥ 1 answers allowed]*

Release alive Discard dead Eat Sell part Sell whole

Other: ____________________

4. Do dolphins **damage** your fishing gear? Yes No Don't Know

5. How do dolphins **affect** your fishing? ____

6. How do you describe dolphin's **population trend** in this year compared to the previous year?

Increasing Same Decreasing Don't Know

Whale Questions

1. Have you ever caught **whales** using your fishing gears in the last year (12 months)?
[Show illustrations, circle one, if answer is "No" or "Don't Know" skip to next section]

Yes No Don't Know

2. For each of the following whale type in the table; within the last year (12months):
    2.1 **How many** whales did you catch in total with **all of your gears** and only **main gear**?
    2.2 What **months** and **where** did you catch them?

[Circle "All whales" first to record the overall catch no. > then ask the fishermen in further (use the illustrations) if they can identify the species / if they can't identify, skip to no.3]

Species	Months caught	Caught no.	Gear caught	Location caught
All whales	J F M A M J J A S O N D			
Kogia	J F M A M J J A S O N D			
False killer	J F M A M J J A S O N D			
Melon-headed	J F M A M J J A S O N D			
Bryde's	J F M A M J J A S O N D			
Ginkgo-Tooth	J F M A M J J A S O N D			
	J F M A M J J A S O N D			
	J F M A M J J A S O N D			
	J F M A M J J A S O N D			
	J F M A M J J A S O N D			

3. What did you **do** with the whales you caught? *[Open question / ≥ 1 answers allowed]*

Release alive Discard dead Eat Sell part Sell whole

Other: ____________________

4. Do whales **damage** your fishing gear? Yes No Don't Know

5. How do whales **affect** your fishing? ____

6. How do you describe whale's **population trend** in this year compared to the previous year?

Increasing Same Decreasing Don't Know

Dugong Questions

1. Have you ever caught **dugongs** using your fishing gears in the **last 5 years**?
[Show illustrations, circle one, if answer is "No" or "Don't Know" skip to next section]

Yes No Don't Know

2. For dugongs; within the **last 5 years**:

2.1 **How many** dugongs did you catch in total with **all of your gears** and only **main gear**?
2.2 What **months** and **where** did you catch them?

[Circle "All rays" first to record the overall catch no. > then ask the fishermen in further (use the illustrations) if they can identify the species / if they can't identify, skip to no.3]

Year	Months caught	Caught no.	Gear caught	Location caught
All years	J F M A M J J A S O N D			
2017	J F M A M J J A S O N D			
2016	J F M A M J J A S O N D			
2015	J F M A M J J A S O N D			
2014	J F M A M J J A S O N D			
2013	J F M A M J J A S O N D			
2012	J F M A M J J A S O N D			

3. What did you **do** with the dugongs you caught? *[Open question / ≥ 1 answers allowed]*

Release alive Discard dead Eat Sell part Sell whole

Collect tear Collect teeth Collect oil Other: ____________________

4. Do dugongs **damage** your fishing gear? Yes No Don't Know

5. How do dugongs **affect** your fishing? ____

6. How do you describe dugong's **population trend** in this year compared to the previous year?

Increasing Same Decreasing Don't Know

Background Questions

1. Have you previously participated in **research** related to:

Fishing Dolphins Whales Dugongs Sharks

Rays Sea turtles None of these

If yes, describe: ____

2. For how many **years** has you been fishing? ____________________

3. Is fishing your **primary** occupation? Yes No

4. Is fishing your **only** occupation? Yes No

If no, what are your other occupations? ____________________

5. What are your fishing **purposes**? ____________________

6. How **far** (km) from shore do you usually fish? ____________________

7. Where are your fishing **areas**? ____

8. Who was your **mentor**? ______________________________

Vessel Questions

1. What **type** of boat do you have? ____________________

2. What **size** is your boat (m)? ____________________

3. What is your boat’s **capacity** (ton gross)? ____________________

4. Is the boat **motorized**? Yes No *[If no, skip to no.7]*

5. What **kind** of motorization? In-board motorized Out-board motorized

6. What is the **horsepower** of the motor? ____________________

7. Is the boat **propelled** by other means? ____________________

8. On average, how many **fishers** are on your vessel when fishing? ____________________

9. Do you use any **log books**? Yes No

10. Are there any **video camera** on your boat? Yes No

11. Do you have a **GPS**? Yes No

12. Do you have a **sounder**? Yes No

13. How do you **communicate** with other fishermen at sea? ______________________________

Future Work Questions

1. In the future, if people want to record fishermen's catches in this village, would you **willing** to let them record it?

Yes No Maybe

2. Would you be willing to have a **video camera** and **GPS** monitoring your fishing activities?

Yes No Maybe

3. Would you be willing to bring a student/observer **on-board** your boat to observe and document your fishing activities?

Yes No Maybe

4. Do you use any **social network** application? Yes No

If yes, choose: Facebook LINE Instagram Twitter WhatApps

E-mail Mobile Others: ____________________

5. Are you happy to **share** your contact details with us? Yes No Yes, but don't remember.

Name: ____

Contact: ____

RBA Questionnaire Interviews

September - December | 2017

Survey Ref. No.	**Date**	**Interviewer**
Location/Village (GPS)		**Occupation**

Interviewee Evaluations

1. How **open** did the fisherman seem about answering bycatch questions?

Very open

Moderately open

Not open

2. How **honest** did the fisherman seem about answering bycatch questions?

Very honest

Moderately honest

Not honest

3. How **interested** did the fisherman seem with the interview?

Very interested

Moderately interested

Not interested

4. How **certain** did the fisherman seem about answers to bycatch **numerical** questions?

Very sure

Moderately sure

Unsure

5. How **certain** did the fisherman seem about answers to bycatch **species** questions?

Very sure

Moderately sure

Unsure

6. What was the overall **expression** the fisherman gave during the interview?

Happy/friendly/interested

Trustworthy/reliable

Aggressive/uncooperative

Defensive/protective/anxiety

Deceivable/untrustworthy

Bored/monotonous/indifferent

Appendix 2

Marine megafauna species identification photobook used in face-to-face interviews with the fishers from 32 small-scale fishing communities in 17 provinces along the Gulf of Thailand and the Andaman Sea, Thailand during September – December 2017. Adapted from Adulyanukosol et al. (2014) and Krajangdara (2017).

Marine Megafauna Species Identification Photobook

RBA Questionnaire Interviews

September - December | 2017

Rays

Wedgefish

Guitarfish

Small sting/whiprays

Guitarfish

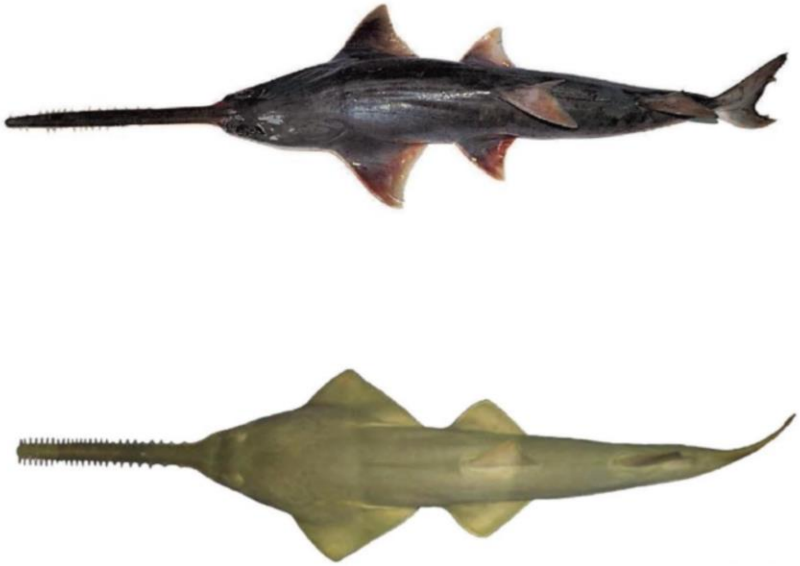
Sting/whiprays

Eagle rays

Devil rays

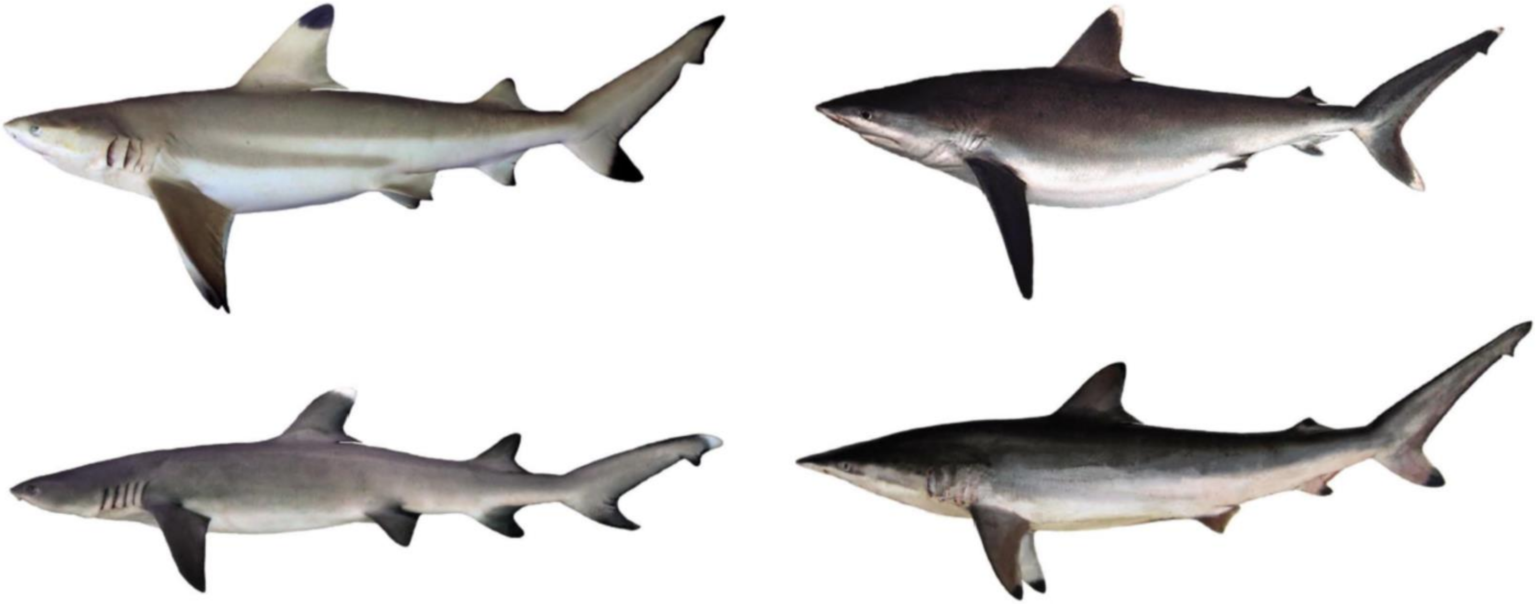
Butterfly rays

Numbfish



Sawfish

Sharks



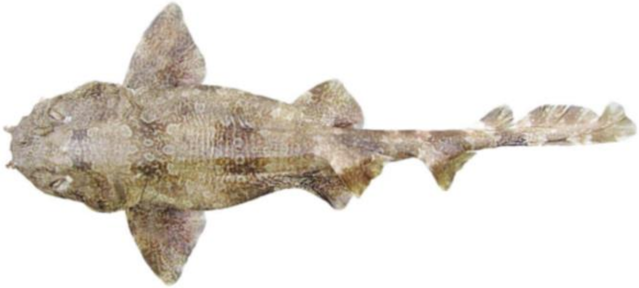
Reef sharks

Bamboo sharks

Gummy sharks

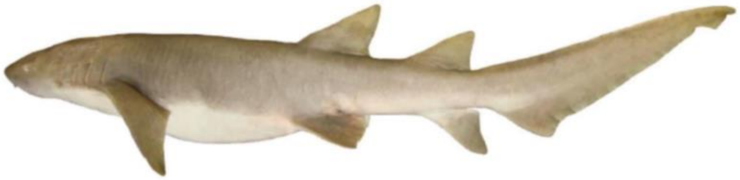
Thresher sharks

Swell sharks



Wobbegong

Angelsharks



Nurse shark

Zebra shark

Sand tiger shark

Hammerhead shark

Tiger shark

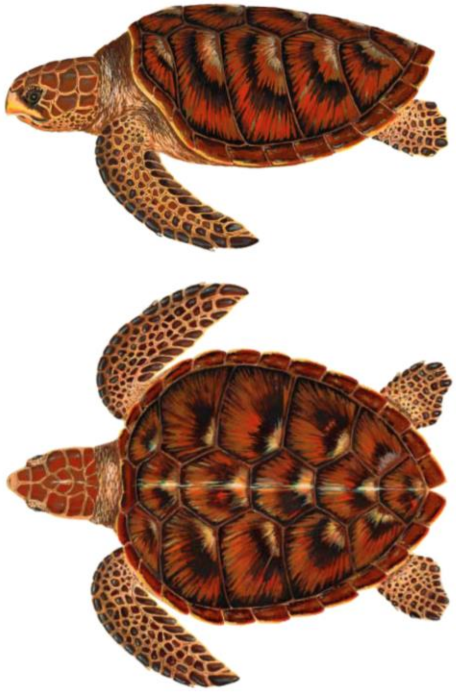
Whale shark

Sea turtles

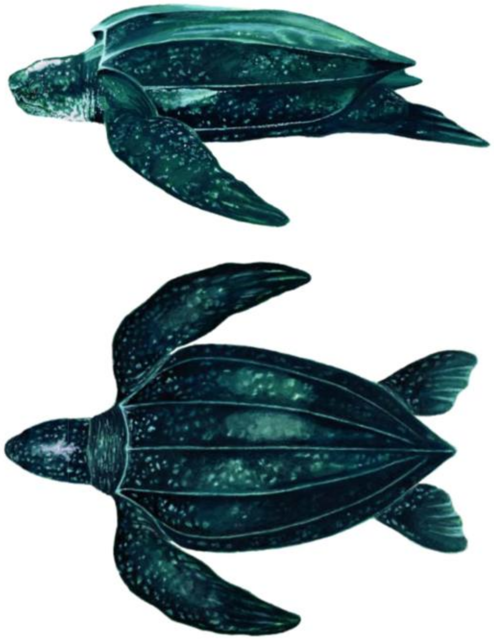
Green turtle

Hawksbill turtle

Olive Ridley turtle



Loggerhead turtle



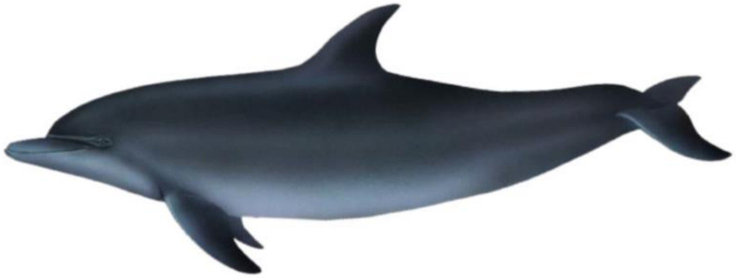
Leatherback turtle

Dolphins & Dugong

Irrawaddy dolphin

Indo-Pacific humpback dolphin

Indo-Pacific finless porpoise



Indo-Pacific bottlenose dolphin

Long-beaked common dolphin

Risso’s dolphin

Striped dolphin

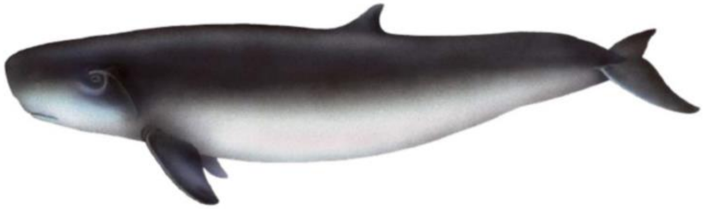
Spinner dolphin

Fraser’s dolphin

Rough-toothed dolphin

Dugong

Whales



Kogia whale

False killer whale

Melon-headed whale

Ginkgo-toothed beaked whale

Killer whale

Cuvier’s beaked whale

Bryde’s whale

Humpback whale

Appendix 3

Small-scale fisheries effort (number of small-scale fishing vessel per gear type) in 24 provinces along the Gulf of Thailand and the Andaman Sea recorded in Thai official fisheries statistics (CG = crab gillnets, LL = longlines, MG = mackerel gillnets, PN = push nets, QFN = squid falling nets, STN = shrimp trammel nets, XG = other gillnets, XLN = other lift nets, XN = other nets and XX = other gears) (DOF 2016).

Zone	**Province**	**Gear**										
		CG	**LL**	**MG**	**PN**	**QFN**	**STN**	**XG**	**XLN**	**XN**	**XX**	**Total**
Gulf of Thailand (GOT)	Trat	294	53	70	1	182	496	42	0	0	1	**1139**
	Chantaburi	237	50	2	0	102	82	262	0	0	177	**912**
	Rayong	731	0	28	0	336	14	260	0	4	0	**1373**
	Chonburi	336	0	99	7	146	76	42	0	0	5	**711**
	Chachoengsao	10	0	0	9	0	1	39	0	0	3	**62**
	Samut Prakan	1	0	0	39	2	0	92	0	0	0	**134**
	Bangkok	1	0	0	1	2	1	1	0	0	0	**6**
	Samut Sakhon	0	0	0	45	22	0	21	0	0	0	**88**
	Samut Songkhram	7	1	1	8	2	0	26	2	0	0	**47**
	Phetchaburi	104	0	4	14	6	0	39	69	0	4	**240**
	Prachuap Khiri Khan	111	0	165	0	751	38	37	0	0	3	**1105**
	Chumphon	59	3	45	0	482	12	216	0	0	0	**817**
	Surat Thani	365	1	0	48	91	54	117	0	0	0	**676**
	Nakhon Si Thammarat	20	1	0	3	11	149	305	0	0	0	**489**
	Phatthalung	45	0	0	0	22	3	38	0	0	3	**111**
	Songkhla	450	0	28	0	28	122	1146	0	0	0	**1774**
	Pattani	715	0	799	3	10	597	338	0	0	0	**2462**
	Narathiwat	0	0	5	0	6	0	37	0	0	0	**48**
	Total	**3486**	**109**	**1246**	**178**	**2201**	**1645**	**3058**	**71**	**4**	**196**	**12194**
Andaman Sea (AS)	Satun	178	1	9	0	55	117	99	0	0	0	**459**
	Trang	171	0	28	0	5	29	91	0	0	110	**434**
	Krabi	10	0	44	0	40	285	122	0	0	0	**501**
	Phuket	70	6	0	0	9	7	178	0	0	0	**270**
	Phang Nga	47	8	14	0	44	117	210	3	0	0	**443**
	Ranong	104	42	8	0	19	100	372	0	0	0	**645**
	Total	**580**	**57**	**103**	**0**	**172**	**655**	**1072**	**3**	**0**	**110**	**2752**
	Grand total (GOT + AS)	**4066**	**166**	**1349**	**178**	**2373**	**2300**	**4130**	**74**	**4**	**306**	**14946**